Engineering Review of Alternative Onsite Wastewater Systems

Report No. 193

MONTANA University System

WATER RESOURCES CENTER

Engineering Review
of
Alternative Onsite Wastewater Systems

Report No. 193

by

Gretchen Rupp

Montana State University - Extension Engineering

Final Report Submitted to the
MONTANA University System WATER RESOURCES CENTER
Montana State University
Bozeman, Montana

1996

The project on which this report is based was financed in part by the Department of the Interior, U. S. Geological Survey, through the Montana University System Water Resources Center as authorized under the Water Resources Research Act of 1984 (PL98-242) as amended by Public Law 101-397.

ENGINEERING REVIEW

Alternative On-Site Wastewater Treatment Systems

by

Mark Brooks

Department of Civil and Agricultural Engineering
Montana State University

June 1996

ENGINEERING REVIEW

Alternative On-Site Wastewater Treatment Systems

by

Mark Brooks

Department of Civil and Agricultural Engineering
Montana State University

June 1996

Contents

Tables

Tables - continued

FIGURES

ABBREVIATIONS

#E*	#x10*
ASTM	American Society for Testing and Materials
BOD	biochemical oxygen demand
C_U	coefficient of uniformity
CFU	colony-forming unit
COD	chemical oxygen demand
CWS	constructed wetland system
D_{10}	10th percentile sand grain size
DEQ	Montana Department of Environmental Quality
DNC	denitrifying chamber
EPA	U.S. Environmental Protection Agency
ET	evapotranspiration
ETA	evapotranspiration-absorption
FC	fecal coliforms
FWS	free water surface
gpd	gallons per day
HLR	hydraulic loading rate
ISF	intermittent sand filter
LOG	power of 10
mg/l	milligrams per liter
MPN	most probable number
N	nitrogen
N_2	nitrogen gas
NH_3	ammonia
NRS	nitrogen removal system
NSF	National Sanitation Foundation
OLR	organic loading rate
O&M	operation and maintenance
PPS	package plant system
TKN	total Kjeldahl nitrogen
RGF	recirculating gravel filter
RSF	recirculating sand filter
RTF	recirculating trickling filter
SF	subsurface flow
STE	septic tank effluent
TC	total coliforms

Abbreviations - continued

TP	total phosphorus
TSS	total suspended solids
UF	upflow filter

ACKNOWLEDGEMENTS

The purpose of this project was to produce a reference document for Montana public officials who review proposals for on-site wastewater systems and promulgate regulations concerning the systems. An advisory committee devoted many hours to assuring that the work targeted the most pressing problems, and resulted in a useful document. The investigators are extremely grateful for the guidance of:

Ken Cope MT Dept. Environmental Quality	Pat Burke MT Dept. Environmental Quality
Randy Triem MT Dept. Environmental Quality	David Jones DJ Engineering
Ray Center Rocky Mountain Engineers	Tim Roark Gallatin Co. Environmental Health Dept.

Many county sanitarians in Montana, and state and provincial officials across North America also took time to answer questions and share unpublished data. Our thanks to all of these people. Mistakes or shortcomings in this report are our responsibility, not theirs.

Gretchen Rupp
Mark Brooks

Bozeman, Montana

June 1996

ABSTRACT

The project investigated the functioning of alternative on-site wastewater systems. The types of systems examined qualify in Montana as "innovative or "experimental" alternative systems: intermittent and recirculating sand filters, sand mounds, evapotranspiration systems, aerobic package plants, nitrogen removal systems, and constructed wetlands. Information on these systems was sought from published literature (design manuals), periodicals, conference proceedings and research reports), through personal contacts with private and university engineers and public officials, and through formal surveys of sanitarians and state/provincial officials. For each type of system, the following questions were addressed:

- On what basis is system performance judged?
- What level of performance can be expected of these systems?
- How do design factors influence system success or failure?
- What adaptations are used in cold climates?
- What is the role of installation and maintenance in system success or failure?
- What questions remain to be answered about system design and performance?

The investigators evaluated the ramifications of recent and ongoing studies for Montana wastewater management practices.

INTRODUCTION

PROJECT PURPOSE AND SCOPE

Approximately 300,000 of Montana's 850,000 residents live in areas not served by sewer systems. Traditionally their wastewater has been treated by septic tank/drainfield systems. These systems are unsuitable for sites with very permeable or impermeable soils, high groundwater, or nearby surface waters. The increased development of areas with marginal soils combined with Montana's new non-degradation rules have increased the use of "alternative" on-site wastewater treatment systems. These are systems referenced in Montana Circular WQB-5 under the Experimental Alternative Systems section (1). They are essentially forms of secondary treatment for septic tank effluent before disposal into the environment.

Alternative systems are proposed more and more frequently by developers, and regulatory agencies must make decisions about permitting them. The assessment of the applicability of these systems in Montana's soils and climate is often difficult. Engineering performance data and system operating records are scattered and hard to obtain. What data exist are often not applicable to Montana's conditions. Consequently, it's difficult for regulatory agencies to justify approving some alternative system proposals. Sometimes projects are denied even though they provide environmentally sound options. It also happens that alternative system technology is sometimes misapplied.

The purpose of this project was to assemble and interpret operating data for alternative wastewater systems, to assist permitting authorities. This report assembles information on several different types of alternative systems. Testimonials about successes and failures with alternative systems have been sought from state officials and private

companies. Research from universities and institutes is also utilized. The literature of often-cited papers and texts is reviewed to establish the "state of the art" for these systems.

The findings are directed towards county sanitarians and permitting authorities at the state level. Reference data and current information should aid in making informed judgments on project proposals. These results and reference material should also be of use to consulting engineers and Extension Service personnel who respond to citizens' questions.

The selection of the types of alternative systems to include in this study was based on the needs of Montana officials. There are many different forms of secondary treatment and volumes of information available on some. Priority was given to systems based on two criteria: (i) the frequency with which a type of system is reviewed for permitting (ii) the need for material to base permitting decisions upon. An advisory committee was assembled to aid in selecting system types. The committee consisted of:

- two consulting engineers who design alternative on-site systems;
- a sanitarian from Gallatin County;
- two specialists from the Montana Department of Environmental Quality, Water Quality Division.

Many types of alternative systems were considered for evaluation. The separation of greywater from household waste for reuse is being successfully implemented in many states, but the current Montana plumbing code does not allow for this and the code is not due for revision for several years (2). Subsequently, this excluded many types of systems from this review. There are many other new technologies being tested for on-site wastewater disposal, but only those that are currently legal according to DEQ regulations were evaluated at length. Other systems that have shown excellent performance and might one day be considered for

use in Montana are also mentioned in this review. The systems chosen for evaluation, in order of priority, are:

1. Intermittent and recirculating sand filters (ISFs and RSFs)
2. Elevated sand mounds (mounds)
3. Evapotranspiration and evapotranspiration-absorption systems (ET & ETA)
4. Nitrogen removal systems (NRSs)
5. Aerobic package plant systems (PPSs)
6. Constructed wetland systems (CWSs)

The first three of these are defined fully in Montana circular WQB-5 (1). Package plant systems are pre-engineered secondary treatment systems that are sold and implemented as a self-contained unit. "Nitrogen removal systems" are defined here as systems that are engineered specifically to increase the nitrogen removal in septic tank effluent. To distinguish these systems from what are called package plants, the systems in this category are constructed using materials that can generally be found in any plumbing supply store. Wetland systems often fall into the jurisdiction of surface discharging systems and are permitted by different authorities than permit the rest of the alternative systems. However, they are becoming increasingly popular for use with small communities even in northern climates, so they will be evaluated in this context. Non-discharging lagoons are widely used in Montana, but due to their simplicity and the lack of current research they are omitted from this review.

The evaluation of these systems incorporates several steps. The first step is to review the commonly-used design manuals/directives. A comparison allows one to see if design and operation parameters for a particular type of system are generally homogenous

around the country. If design criteria are significantly varied from one directive to the next, it is difficult to compare data from various locations.

The second step is to establish system peformance expectations. From the early 1970s through the mid-1980s, there was much more funding for research into different types of alternative wastewater treatment systems (4). The level of treatment that alternative systems are now expected to provide was generally established in these earlier studies.

The third step in the evaluation of each alternative system is to evaluate current research and monitoring projects, to assess whether the systems are operating at expected levels of performance. Current research (1990s) is scarce and the sources very scattered. Research has increasingly been left up to private companies and universities, since the EPA's funding of research for wastewater engineering activities has gone from a peak of about $19 million in 1979 to less than $1 million in fiscal year 1993 (4). While there may be many current research projects for a particular system, only a few are presented here. The projects chosen for review illustrate a common problem or solution noted by several studies. For example, the data from one project suggest that a customary loading rate might be too high. This particular project was specifically included because conversations with professionals and other documentation and/or experiences support the same conclusion. Eachof the projects included is indicative of a consensus about the operation of the particular alternative system.

The fourth and final step is to assess the ramifications of current research to the alternative system's application in Montana. This section summarizes the main points made about a system's application, and makes suggestions about how Montanans can avoid problematic aspects of system application. Suggestions are made for further work to address unanswered questions about system performance.

BACKGROUND INFORMATION

How is wastewater system performance judged? With some types of alternative systems, such as sand filters, performance is quantified by percentage removals of "performance parameters." Parameters such as BOD_5, total suspended solids (TSS), nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen (TKN), and total phosphorus (TP) are often cited and are referred to in this review as common performance parameters. With other types of systems, such as ET and ETA, performance is usually gauged by the presence or lack of surfacing effluent. Wherever possible, quantitative results are used in this review to evaluate performance. Historically, most officials at the local level have accepted the concept that good performance is analogous to effective disposal. This pragmatic approach reflects the general a lack of funding and personnel to document performance. This "out of sight, out of mind" approach is currently changing as contaminant-specific regulations are developed and enforced.

Definitions of some performance parameters that may be of help to the reader are:

- Total Kjeldahl nitrogen - this test quantifies the sum of organic nitrogen, ammonia nitrogen and ammonium nitrogen. TKN plus nitrate N equals total N (nitrite - N is usually inconsequential).
- Total coliforms - the concentration of coliform bacteria in the wastewater, quantified as colony-forming units per 100 milliliters. Coliform removal in a treatment unit is described logarithmically: one log = 90 percent removal, 2 log = 99 percent, etc.
- Fecal coliforms - the wastewater concentration of coliform bacteria of fecal origin, also measured in CFU/100 ml.

Assays of coliform bacteria are used a surrogate measures of the presence of pathogenic micro-organisms, which are much more difficult to test for. Untreated domestic wastewater contains 10^6 - 10^9 CFU/100 ml total coliforms.

The common operational and design parameters also need to be defined. The hydraulic loading rate (HLR) is the flow the secondary treatment system receives on a daily basis (gallons per day) per square foot of area (ft^2) over which effluent is applied. The organic loading rate (OLR) is the amount of organic material applied to the system. This is usually measured in terms of biochemical oxygen demand (BOD_5). In the BOD test, the amount of organic matter present is described by the amount of oxygen that microbes use in degrading it over the course of five days. Organic matter is sometimes described in terms of chemical oxygen demand (COD). COD is the amount of oxygen needed to oxidize all the organic matter to CO_2 and water; it is always greater than BOD. Media grain sizes are often referred to by their effective size, or D_{10}, which is the size of the grains (in millimeters) such that 10% by weight are smaller. Another media specification is the uniformity coefficient (Cu) which is the ratio of grain size that has 60% by weight finer than itself to the size which has 10% finer than itself. The greater the value of Cu, the more alike the sizes of the sand grains. Effective grain size and size distribution play an important role in the hydraulic conductivity of effluent through the media.

The transformations of nitrogen through the wastewater treatment/disposal system are discussed extensively in this report. This is because final levels of nitrate-nitrogen are often the driving factor in system selection and configuration. Excessive nitrate consumption causes methemoglobinemia, a potentially fatal disorder in which an infant's oxygen-transport capability is disrupted. A related problem was recently reported: In 1993 two episodes of

nitrate poisoning were associated with eight miscarriages in Indiana (60). Many states have adopted a 10 mg/l discharge standard for nitrates in sensitive areas (6). In Montana the standards are based on background levels of nitrate and the degree to which nitrate inputs will affect these levels after travel through a "mixing zone" (7). Many new on-site technologies have been developed specifically to meet the more stringent nitrate contamination criteria.

The subject of nitrogen removal in on-site systems is often misunderstood, and it is appropriate to review the process briefly here. Nitrogen entering the septic tank is usually in the form of organic-N and ammonia-N (5). Ammonification occurs in the septic tank, resulting in effluent containing primarily ammonia-N, (or ammonium-N depending upon pH). In conventional systems, the ammonia-N is rapidly converted to nitrate-N by the biological process of nitrification in the soil absorption field. Soil cation exchange mechanisms do not affect the nitrate anion and it moves relatively freely in the soil profile, possibly percolating into groundwater or nearby surface waters. Actual removal of nitrogen from the wastewater requires transforming nitrogen into gas form. Starting with ammonia-N, this is a two step process. **Nitrification** of ammonia into nitrites, and eventually nitrates, must first be performed by a specific group of autotrophic microorganisms in an aerobic environment. Next, the nitrate-N must be converted to nitrogen gas in the **denitrification** process via two gaseous intermediates. This requires anoxic conditions (the absence of free oxygen) and a carbon source. The heterotrophic microorganisms use the nitrate as their electron acceptor in the respiration process, and reduce the nitrate to nitrogen gas. The gas is then free to disperse into the atmosphere. Only by incorporating both nitrification and denitrification will nitrogen be truly <u>removed</u> by the wastewater treatment process. This fact illustrates many

TABLE 1
PERFORMANCE DATA

ADAPTED FROM: Oregon Final Report (15)
System: residential septic tank effluent

SYSTEM
REFERENCE:

Avg. Flow (gpd)		191	113	188	176	161	174	164
Temp.	infl.							
deg. C	effl.							
BOD5	infl.							
mg/l	effl.	149	197	188	378	125	348	217
TSS	infl.							
mg/l	effl.	240	38	79	276	91.7	171	146
AMMONIA-N	infl.							
mg/l	effl.	37.8	35	35.5	53.3	36.1	55.9	40.6
NITRATE-N	infl.							
mg/l	effl.	0.18	0.81	0.04	0.16	0.56	0.02	0.4
TKN	infl.							
mg/l	effl.	56.9	58.4	45.6	71.8	51.3	70.5	57.1
TOTAL N	infl.							
mg/l	effl.	57.1	59.2	45.67	71.9	51.8	70.9	57.5
T. PHOSPHATE	infl.							
mg/l	effl.							
T.COLIFORM	infl.							
CFU/100ml	effl.	1.5E+05	1.80E+06	7.7E+05	2.10E+07	9.90E+05	1.00E+06	1.32E+06
F.COLIFORM	infl.							
CFU/100ml	effl.	2.00E+04	1.10E+05	7.0E+04	5.4E+05	8.00E+04	1.00E+06	2.60E+05

problems with claims of nitrogen removal in on-site systems. Nitrogen is sometimes claimed to be completely removed from the waste stream when there is no ammonia present in the effluent. Complete conversion of the ammonia to nitrate may have occurred, but the nitrate-N can still be problematic. Extravagant claims for nitrogen removal by intermittent sand filters must also be examined critically. Those systems are not engineered to provide the anaerobic conditions required to transform nitrate into nitrogen gas.

Establishing the characteristics of septic tank effluent is necessary for this review. The purpose of the septic tank is to remove settlable solids and floating scum from the waste stream and degrade some of the non-settlable solids by anaerobic digestion. Most organic nitrogen is converted to ammonia in the septic tank. Typical single-household effluent characteristics can be seen in Table 1. For this review, the alternative system influent is always septic tank effluent since all of the systems examined utilized some sort of preliminary treatment prior to secondary treatment. Whenever possible, data for secondary treatment influent (septic tank effluent) performance parameters are included in the data tables. In studies where these data are not available, typical septic tank performance parameter values can be assumed.

One final note: company and trade names are used extensively in this review. This is unavoidable in a field where the products and devices are made by relatively few manufacturers. No endorsement should be inferred from these references.

SAND FILTERS

Two types of sand filters are used for on-site systems. **Intermittent sand filters** (Figure 1) are stratified sand and gravel beds that are dosed with septic tank effluent several times a day. The downward-percolating wastewater is cleansed by physical, chemical and biological processes. It collects at the base of the filter, and is routed to a drainfield. **Recirculating sand filters** employ a separate recirculation tank to collect the filtered wastewater. It can then be dosed to the filter again, or sent to the drainfield. Figure 2 is a schematic of a recirculating sand filter system. These systems are frequently installed where wastewater organic strength is expected to be high.

Sand filters are the form of secondary treatment that has received the most attention, particularly in the Northwest, in recent years. This is ironic in that this is also one of the first forms of secondary treatment used in this country, dating back to 1889 in Massachusetts (8). Despite their "experimental" classification in Montana Circular WQB-5 (1), sand filters are routinely permitted and installed (see Appendix A). However, their complexity should not be underestimated. The fact that these systems are biologically-based is ignored by design directives based on separation lengths, dimensions and volumes. Although the interrelations of hydraulic and organic loading rates, media surface area, and biological metabolic rates are the factors that determine performance, they are not yet all quantitatively understood. Nonetheless, these systems appear to have a good performance record. This has led to dramatic increases in their use. Data, research, and experience are more abundant for sand filters than for any other system. Many see the performance of sand filters as well-established and are focusing their efforts on improving design standards. Recent technological

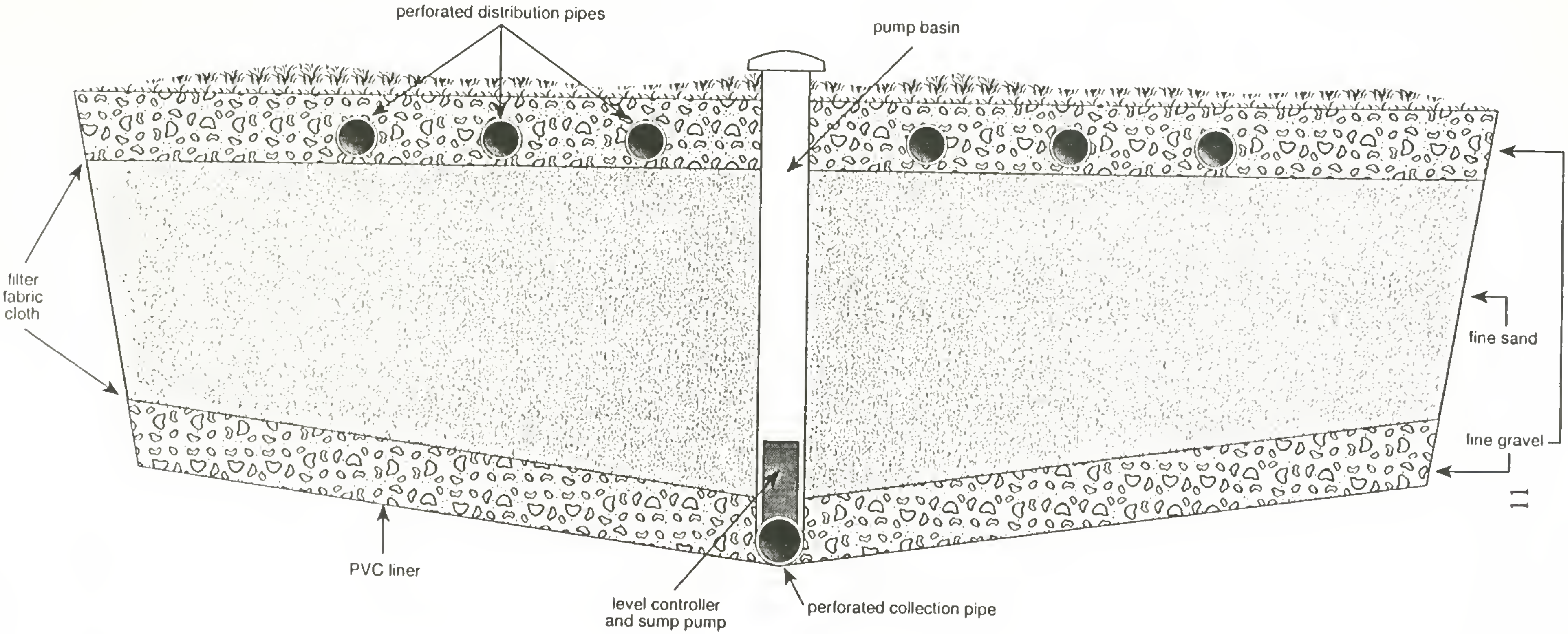

Figure 1. Intermittent Sand Filter

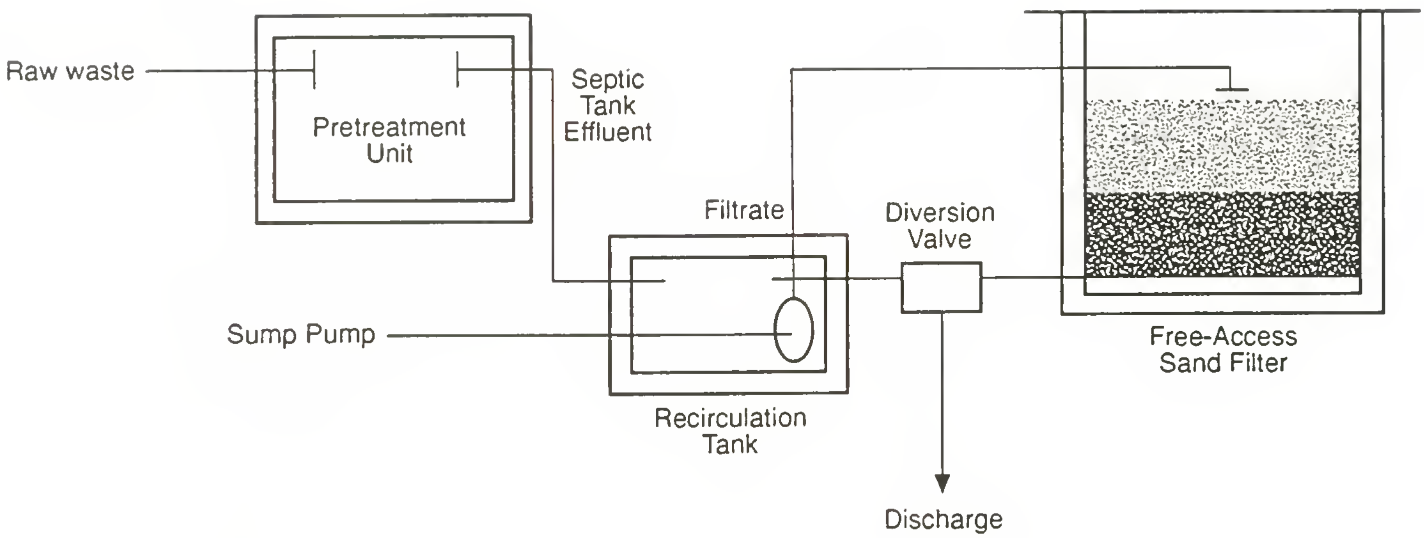

Figure 2. Recirculating Sand Filter

advances have made designs more "maintenance friendly." Recent research has focused on manipulating system variables such as dosing frequency and sand grain size to optimize performance. Also, reducing bed size and other cost-reduction measures are on the forefront of research and development.

DESIGN CRITERIA

Many sources can be consulted for sand filter design criteria. Most sources are consistent with each other in their design specifications, but small discrepancies exist. Discussed below are some of the more commonly-referred-to manuals. To evaluate performance, the review examines the most critical design and operating criteria: hydraulic loading rate (HLR), organic loading rate (OLR), media grain size, dosing, maintenance recommendations and certain unique suggestions (Tables 2 and 3).

INTERMITTENT SAND FILTERS

<u>1980 EPA Design Manual</u> (3)

Design specifications in this publication form the basis for more current design adaptations. The manual lists broad ranges for certain specifications, such as sand size, that are more specific in current documents. The only maintenance directives specified are resting, raking and replacing the media, but "the effectiveness is not known".

TABLE 2

INTERMITTENT SAND FILTER DESIGN SPECIFICATIONS

DIRECTIVE	HLR	OLR	MEDIA SIZE	DOSING	OTHER RECOMMENDATIONS
1980 EPA Design Manual	.75 - 15 gpd/ft^2	ng	0.25mm - 1.5mm	"more than 2 doses/day"	
Montana's WQB5	max 1.2 gpd/ft^2	ng	ASTM C-33	max 4 doses/day	pressure dosing required 50% drainfield reduction allowed
Washington Guidelines	max. 1.2 gpd/ft^2	BOD5 < 230 mg/l	ASTM C-33 sand	4 doses/day	strongly recommend O&Mcontract 50% drainfield reduction allowed
Small Flows Design Module #6	max 1.0 gpd/ft^2	depends on HLR	0.5mm - 1.0mm	2 doses/day	
"Orenco, Inc."	.5 - 2 gpd/ft^2	ng	use sizing chart	every 30 min.	many; see text

ng = none given

MT Circular WQB-5 (1)

Criteria given here are generally in agreement with other current directives. One criterion that has been called into question by research is a maximum allowable dosing frequency of 4 doses/day. Pressure dosing is required, which is in agreement with most other states' recommendations. A 50% drainfield area reduction is given which is also common in other states.

Washington State Guidelines (9)

Washington's laws are very similar to Montana's, but the State provides a very lengthy and descriptive guideline directive that makes many recommendations for proven procedures employed in successful ISF applications. One of the more adamant recommendations is for homeowners to employ an Operation & Maintenance (O & M) Contract with a trained professional to service their system regularly.

Small Flows Design Module #20 (10)

This directive was published as an update to the 1980 EPA Manual. It recommends that the hydraulic loading rate not exceed 1.0 gpd/ft^2, and that the loading rate be a function of wastewater strength (organic matter content).

Orenco Systems, Inc. (11)

Orenco's directives deviate from "cookbook" recipes for sand filter design towards more engineered systems. Few design criteria are said to be applicable to all situations. Charts and tables are used to coorelate sand size and bed area to hydraulic loading and

organic loading. Orenco strongly emphasizes the fact that their design criteria are part of an integrated system and application of their whole design is necessary to insure maximum performance. Many improvements have been developed by Orenco that have greatly reduced occurrence of system failures. Some of these improvements include: high head pumps, smaller diameter laterals, valves to flush filter laterals, easy access risers, orifice shields, many control panel features, screened pump vaults, and many cold climate adaptations.

RECIRCULATING SAND FILTERS

Less design information is available for RSFs than ISFs, despite the fact they are more complex. Listed below is a sampling of directives that are representative of the level of detail and sophistication one may find (Table 3). In addition to the design and operation criteria evaluated for ISFs, recommendations concerning the recirculation ratio are also examined. This is the ratio of total flow sent through the sand filter to the incoming flow of septic tank effluent (24). The dosing recommendation from each directive calls for dosing every 30 minutes.

1980 EPA Design Manual (3)

As one of the most dated directives, this manual has a level of detail that is marginally adequate for design purposes. Its specifications are taken from a 1968 developmental RSF described by Hines & Favreau (12). This design is still used as the basis for current designs.

TABLE 3

RECIRCULATING SAND FILTER DESIGN SPECIFICATIONS

DIRECTIVE	HLR	OLR	MEDIA SIZE	RECIRC. RATIO	OTHER RECOMMENDATIONS
1980 EPA Design Manual	3 - 5 gpd/ft^2	ng	0.3mm - 1.5mm	5 to 1	
Montana's WQB5	max - 3gpd/ft^2	ng	sand rather than gravel	4 to 1	
Washington Guidelines	1150/BOD5 of s.t.e.	230mg/l < BOD5 < 300mg/l	3mm < D10 < 5mm	4 to 1	used for light commercial applications
Orenco, Inc.	max = 5 pgd/ft^2	BOD5 < 300mg/l	1.5mm - 2.5 mm (pea gravel)	5-3 to 1	many, see text
Michigan State	3 gpd/ft^2	ng	0.2mm < D10 < 0.3mm	5-3 to 1	several cold climate adaptations; see text

MT Circular WQB-5 (1)

Most of the information in this document is in agreement with other directives. However, WQB-5 mentions that the media used should be "sand rather than gravel." Many other directives recommend gravel rather than sand, but never the opposite. Other operation parameters are comparatively consistent.

Washington State Guidelines (9)

Washington designates the recirculating sand filter for a very specific application: light commercial use. Its directives recognize the fact that RSFs can handle a larger organic loading than ISFs. They also assume that a commercial establishment can more easily afford an O & M contract, which is very desirable as this system is more sophisticated than an ISF.

Orenco Systems, Inc. (11)

Orenco's recommendations are generally consistent with other directives. The higher HLR shown in Table 3 is qualified by saying it is for a BOD_5 of less than 180 mg/l. They list other influent parameter maximum values that should not be exceeded for RSF application: (i) $BOD_5 < 300$ mg/l, (ii) oil and grease < 25 mg/l, (iii) and TSS< 150 mg/l.

Michigan State Research (13)

Michigan State University has been at the forefront of RSF research, and has compiled extensive data on their use in cold regions. These recommendations assume RSF application in cold regions. Pertinent recommendations include less frequent dosing at night

to conserve heat in the system, complete draining of the transfer system between doses, and placing the bottom of the media well below frost level.

ESTABLISHED PERFORMANCE LEVELS

The literature indicates that intermittent and recirculating sand filters can consistently achieve the following effluent quality:

BOD_5	< 20 mg/l	
TSS	< 20 mg/l	
AMMONIA-N	< 10 mg/l	
T. COLIFORMS	99 %	(2 log) removal

Other nutrient removal values are less well-established. It is sometimes stated that expected sand filter effluent levels of BOD_5 and TSS are less than 10 mg/l, but examination of a wide range of current field data shows that these levels are routinely exceeded, as discussed below.

It is appropriate to review in some detail the studies that established currently-accepted standards. Examining these sometimes-dated studies (pre-1990) will allow establishment of a "baseline" by which to judge current research and monitoring projects. Most of the studies discussed here are commonly cited by investigators in the field when stating expected performance. Hence, they are referred to herein as "baseline" studies.

1980 EPA Design Manual (3)

The 1980 EPA Design Manual is probably the most-often-cited reference concerning performance of sand filters. The performance data for ISFs and RSFs can be seen in Table 4.

TABLE 4
PEFORMANCE DATA

ADAPTED FROM: 1980 EPA Design Manual (3)
SYSTEM: ISF & RSF

REFERENCE:		25	25	25	25	25	24
TYPE		ISF	ISF	ISF	ISF	ISF	RSF
HLR (gpd/ft^2)		1	1	1	1	1	
Temp.	infl.						
deg.C	effl.						
BOD5	infl.						
mg/l	effl.	2	4.7	3.8	4.3	8.9	4
TSS	infl.						
mg/l	effl.	4.4	3.9	4.3	4.9	12.9	5
AMMONIA-N	infl.						
mg/l	effl.	0.3	3.8	3.1	3.7	6.7	
NITRATE-N	infl.						
mg/l	effl.	25	23	27	24	18	

Intermittent Sand Filters:

The figures for ISFs are based on the 1975 publication by Brandes, Chowdry and Cheng (14). While the systems are efficient at nitrification, the EPA manual states that there is "little or no denitrification" in sand filters. There are no data for phosphorus removal, but the text states that while there is significant initial phosphorus removal with new sand, there is "low phosphate removal in a mature filter." Phosphorus removal is said to be primarily a function of the assimilative capacity of the media for phosphorus.

The principal purpose of the Brandes research was to study the affects of additives on BOD, phosphorus, and nitrogen removal. Several conclusions were drawn about the effects of different additives, but the investigators did not draw conclusions about the overall performance of ISFs. Samples were taken for a 13 week period, which cannot be considered long term. Ten filter beds were constructed with sand sizes ranging from $0.24mm < D_{10} < 2.5mm$. These were all dosed at 1 gpd/ft^2. These design criteria all appear to be close to values currently used in the field, so the study's results for performance should be valid. However, the effects of some of the chemical additives used in the study were ot plainly separated from other independent variables. This study does not form a sound basis for the EPA manual's conclusions regarding ISF performance.

Recirculating Sand Filters:

The EPA design manual's figures are based on the often-cited 1975 study by Hines and Favreau (12). The data are from one of the first RSFs ever designed, from four months of winter monitoring, with no influent sampling. This study was a monumental step in the application of a new on-site technology, but the brevity of testing can only lead to the

conclusion that this particular design has promise. It does not appear that these values for performance parameters should be universally accepted, and more long-term data are needed to concretely establish this system's expected performance.

The 1980 EPA design manual is based on very limited data and should not be used alone to predict the performance of sand filters. However, the cited effluent levels are consistent with those of subsequent studies and could be used to support expected performance levels.

1982 Oregon Final Report (15)

The second most-often-cited source for sand filter performance is the 1982 summary of a seven-year study done by the State of Oregon. At the time it was the most extensive and long-term study of on-site systems. Today it is still the scientific basis for the more liberal permitting of several types of alternative systems.

Intermittent Sand Filters:

The study consisted of monitoring seven systems for periods of 5-49 months. Design specifications were consistent with current applications. There were some small variations in sand size and uniformity. Systems were dosed two to five times per day at various hydraulic loading rates. "Tees" and other design enhancements were implemented to insure proper sampling techniques. All systems functioned without failure, and no maintenance was perfomed on the filters during the period of the study.

The performance data (Table 5) show excellent removal of BOD_5, but slightly higher than expected values in some cases for effluent SS. The elevated effluent solids were

TABLE 5
PEFORMANCE DATA

ADAPTED FROM: Oregon Final Report (15)
SYSTEM: ISF & RSF

SYSTEM REFERENCE: TYPE		A ISF	B ISF	C ISF	D ISF	E RSF	F RSF	G RSF
HLR (gpd/ft^2)		0.57	0.51	0.33	0.48	1.2	1.12	0.9
Temp.	infl.							
deg.C	effl.							
BOD5	infl.	197			139	348	125	378
mg/l	effl.	3	2.7	2.7	6.4	3.8	2.8	3.3
TSS	infl.	38			149	171	91.7	276
mg/l	effl.	2.2	15.4	4	28	3.8	5.1	1.5
AMMONIA-N	infl.	35			37.8	55.9	36.1	53.3
mg/l	effl.	0.2	0.13	0.12	0.7	0.6	0.22	0.44
NITRATE-N	infl.	0.18			0.81	0.38	0.56	0.16
mg/l	effl.	41	25.3	25.5	28.8	38.4	33.2	32.4
TKN	infl.							
mg/l	effl.							
TOTAL N	infl.	59.2			57.1	70.9	51.8	71.9
mg/l	effl.	41.6	26.5	26.7	31.2	39.6	34.1	34.2
T.PHOSPHORUS	infl.							
mg/l	effl.							
T.COLIFORM	infl.							
	effl.							
F.COLIFORM	infl.	1.0E+05			2.0E+04	2.5E+06	1.0E+06	2.0E+06
org/100ml	effl.	537	94	790	30	51	113	41

attributed to lack of screened pump vaults in some systems. The filters showed excellent oxidation of ammonia to nitrate, but the maximum percent change in total nitrogen was only 47%. Again, this is evidence of the predominately aerobic nature of these systems. However, there was some denitrification. The authors attributed this to facultative anaerobes occupying oxygen deficient microsites and using nitrates in respiration. This may have been enhanced by the intermittent dosing, causing temporary saturation and reduced available oxygen. Total coliforms were reduced by 99% on average. In systems where influent coliform levels were abnormally high, the loading rate was reduced by over 50%. The loading reduction allowed total coliform levels and fecal coliform levels to be significantly reduced. The investigators concluded that dosing rates exceeding 0.5 gal/ft^2 dose were likely to cause saturated flow through medium sands, reducing the sands' capacity to treat effluent.

Examination of disposal field trenches downstream from the filters showed no formation of biomat, and subsequently high infiltration rates when compared to those commonly reported for septic tank effluent. This phenomenon has been used as a justification for the drainfield reductions allowed with these systems. The lack of biomat formation is indicative that minimal treatment is performed by the drainfield, because most of the organic material is degraded by microbial activity in the sand filter.

Recirculating Sand Filters:

The designs implemented were similar to those used by Hines and Favreau (12), but a coarser media was tried in this study. A problem encountered with the recirculating filters was accumulation of debris on filter surfaces, since these were open filters. Also, weeding and cleaning was required at least twice annually, but there was no ponding in the filter and

performance did not seem to be affected by debris buildup. There was marked seasonal variation in performance. Greater Total N removal occurred during winter months. This can be attributed to the increased rainfall in Oregon's winter, promulgating more denitrification at anoxic microsites. Also, it should be noted that in Douglas County, Oregon, the average monthly temperature rarely drops below 40° F. This could not be considered "cold climate" by Montana standards. The effluent from these filters was of consistently high quality, and the filters provided relatively consistent Total N removal, averaging 43% (Table 5). The data are consistent with established expected RSF performance. As with ISFs, drainfield infiltration rates were significantly increased compared to accepted septic tank effluent infiltration rates.

The Oregon Report was certainly more scientifically valid than any of its predecessors in establishing long term alternative system performance. Yet, it is still difficult to analyze the data without consideration of the local climate, making universal performance claims difficult. The exceptional performance of the intermittent sand filters used in this study prompted increased acceptance of their use in Oregon and other Northwest states. The recirculating filters also produced excellent effluent quality, but the increased potential for pump failure hindered their widespread use at the time.

1985 EPA Technology Assessment (10)

Another source for sand filter performance data with a broad sampling base is the *1985 EPA Technology Assessment of Intermittent Sand Filters*. This evaluation is based on data from a wide geographical distribution of small community sand filters. The data are

TABLE 6
PEFORMANCE DATA

ADAPTED FROM: 1985 EPA Tech. Assessment (10)
SYSTEM: RSF & ISF

REFERENCE: (state) TYPE		IL ISF	ME ISF	ME ISF	IL ISF	IL RSF	IL RSF	CA RSF
HLR (gpd/ft^2)		13.5	1.75	1.1	3	2.7		5
Temp.	infl.							
deg.C	effl.							
BOD5	infl.	148			30	218		48
mg/l	effl.	11	10	20	4	7	10	2
TSS	infl.	10				62	79	36
mg/l	effl.	2	10	20	5	7	12	11
AMMONIA-N	infl.				22.4		279	
mg/l	effl.				0.7		4.8	
NITRATE-N	infl.				0.7		1	
mg/l	effl.				24.4		27	
TKN	infl.							
mg/l	effl.							
TOTAL N	infl.							
mg/l	effl.							
T.PHOSPHORUS	infl.				8		13.4	
mg/l	effl.				7.2		8.9	
T.COLIFORM	infl.							
	effl.							
F.COLIFORM	infl.				7.2		7.1	
LOG#/L	effl.				5.5		5.7	

taken from monitoring conducted from 1977 to 1983. RSFs and ISFs with different hydraulic and organic loading rates were monitored (Table 6).

The data support the expected performance levels stated (BOD_5 and TSS< 20 mg/l), but some variability exists. In the two systems where nitrogen was monitored, nitrification was thorough, with ammonia-N effectively eliminated and nitrate-N concentrations elevated. While temperature was not a major consideration in this study, the investigators stated that the use of "insulated covers may permit trouble-free winter operation in areas with ambient temperatures as low as -40° F". Maintenance of a filter was briefly discussed: raking and sand removal upon clogging were recommended.

This study was one of the first to compare data from various locations around the country, and the results were surprisingly consistent. The expected performance levels were met by all systems in the study, despite a variety of site locations and design specifications.

<u>*Sand Filters: State of the Art and Beyond*</u> (16)

To conclude the establishment of the "baseline" from which to evaluate current research, we must look at one final often-cited source. Orenco Systems, Inc., has become one of the leaders in sand filter technology and on-site system research. In 1991, company president Harold Ball published *"Sand Filters: State Of The Art And Beyond"*, summarizing what he considers essential components and operation of sand filters, based on his experience. Ball cites the 1982 Oregon Report, as well as Small Flows Clearinghouse databases, in saying that effluent "biological oxygen demand (BOD_5), and suspended solids (TSS) were consistently less than 5mg/l, ammonia less than 1 mg/l, nitrates between 20 and 40 mg/l and fecal coliform bacterial averaged a little more than 400 organisms/100ml." This

review gives evidence that stated effluent levels are slightly lower than these consistently achieved in field applications of sand filters. Ball gives a number of recommendations concerning sand filter components such as high head pumps, screened pump vaults, control panels and alarms, and orifice shields. He notes ongoing research to investigate alternate media types and sizes, in order to reduce overall filter size.

In an updated version of this paper, Ball presents the findings from some of the studies alluded to in 1991 (17). First is that a watertight, single-compartment septic tank with an outlet screening device significantly reduced BOD_5 and TSS levels in final effluent (the effectiveness of septic tank screening devices was also noted recently in a study by Tennessee Tech, where the investigators noted 75% more efficient organic matter removal with a septic tank outlet filter (18)). Next Ball concludes that by "applying small doses of effluent at frequent intervals...it is possible to obtain higher loading rates". This is supported by studies at the University of California-Davis (8). Ball also notes that loading rates are affected by many factors, including wastewater strength (BOD_5 and TSS), orifice size, spacing of dosing frequency, media size and gradation, air temperature and movement. This may seem obvious, but it contradicts the methodology prescribed by many regulatory agencies, in which the code designates specific numerical values for parameters such as hydraulic loading rate without considering factors such as wastewater strength.

Orenco, Inc. probably has as much experience with sand filters as anyone in the field. Their engineering advances are becoming the status quo for effective current designs. Their stated performance levels for sand filters may be the most frequently cited. However, current field monitoring shows these effluent parameter levels to be optimally but not consistently achieved (discussed below).

CURRENT RESEARCH AND MONITORING PROJECTS

Intermittent Sand Filters

Montana's Experience

The Montana DEQ has recently performed "grab" sampling of several ISFs located in Ravalli County (Table 7). The designs used in these systems are not specified, but one can assume they meet requirements set forth by Montana Circular WQB-5. Each system is set in line with a residential household so the influent values shown in Table 1 should be assumed. However, some of the homes sampled were used only as vacation homes. Samples were taken in March, a time when one would expect poor removal efficiency due to cold temperatures.

The most recent sampling consisted of testing five systems for ammonia, nitrate, total Kjeldahl nitrogen, and total phosphorus. Three of the five systems tested showed significant if not complete transformation of ammonia and organic nitrogen to nitrate. Influent as well as effluent data were collected from the other two systems, and the nitrogen species data were internally contradictory. One system apparently experienced a 50% gain in nitrogen, a virtual impossibility. In the other, ammonia exceeded total Kjeldahl nitrogen, indicating that one or the other of the analyses was erroneous. No conclusions can be drawn regarding nitrogen transformation in those systems.

Phosphorus levels may or may not have been reduced in these sand filters; the two paired values are at odds.

TABLE 7
PEFORMANCE DATA

ADAPTED FROM: MT DEQ Sampling
SYSTEM: ISF

REFERENCE: (county)		A	B	C	D	E
HLR (gpd/ft^2)						
Temp.	infl.					
deg.C	effl.					
BOD5	infl.					
mg/l	effl.					
TSS	infl.					
mg/l	effl.					
AMMONIA-N	infl.			20		42.4
mg/l	effl.	1.72	2.82	<.1	0.04	31.2
NITRATE-N	infl.			0.02		0.02
mg/l	effl.	25.8	31.4	29.4	16.6	1.46
TKN	infl.			19.7		39
mg/l	effl.	2.2	3.7	0.4	1.8	24.4
TOTAL N	infl.					
mg/l	effl.					
T.PHOSPHORUS	infl.			4.3		4.43
mg/l	effl.	3.6	6.38	3.8	3.2	0.4

Grab sampling of ISFs in Missoula County by private companies has revealed excellent fecal coliform removal (69). The results of nitrate/nitrite sampling revealed efficient nitrification, with sand filter effluent containing around 40 mg/l nitrate nitrogen. While the recent data generally show the expected nutrient levels in ISF effluent, it is hard to assess the true performance of the filters as there was inconsistent measure of influent quality. The measures of effluent nutrient concentrations can be used to gauge how well organics are being broken down microbially, and possibly to identify a potentially failing system. However, occasional grab samples can only be used to indicate how well the system was operating at the time of sampling. A more comprehensive sampling program with data collected throughout the year would be necessary to draw conclusions about a general effectiveness of the system.

Studies at UC Davis (8)

A more recent attempt to quantify the interrelationships between media size, hydraulic loading rate, dosing frequency, and uniformity coefficient was made at the University of California-Davis in 1991. In this thesis project, the objective was to identify the limits of performance likely to be encountered in attempts to downsize systems and reduce construction costs.

The study began with a thorough review of previous studies where the relationships among these variables were noted. Based on previous studies, the investigator anticipated that more frequent dosing of small amounts would provide improved treatment. He used 12 cell prototypes with two different sand depths (18 and 30 inches), different sand sizes (.29mm < D10 < .93mm), different coefficients of uniformity (1.5 < Cu < 4.52), different HLRs

(1.0, 2.0, 4.0, 8.0, 16 gpd/ft^2), and different dosing frequencies (4, 12, 24 doses/day). The filters were small (animal watering tanks) and they were connected in-line after the university wastewater treatment facility's primary settling tank. The sand filter influent was characterized as weak (Table 8). Temperature was ignored in this study and one potential drawback to the relevance of this study is the fact that the monitoring was in the summer when one would expect higher performance.

Larger sands showed performance equal to smaller sands when small but frequent doses (24 doses/day) were applied. The small doses prevented the lower retention capacity of the larger sand sizes from being a controlling factor. The increased dosing frequency greatly improved the performance of the larger sand sizes, particularly at lower loading rates (HLR < 4 gpd/ft^2). Removal efficiencies for performance parameters were generally within accepted values for intermittent filters with loading rates up to 4 gpd/ft^2. The shallower sand beds showed increased nitrification. The removal of coliform bacteria was found to be identically effective at high dosing rates and lower dosing rates for all sand sizes with uniform sand.

The final recommendations of the study were the use of a coarse sand (0.93mm) dosed 24 times/day with a HLR of up to 4.0 gpd/ft^2. This maximized the quality and amount of wastewater treated per day with the least risk of failure.

The shortcomings of this study are in its scope. The test modules were small, the test duration was only 3 months and testing was conducted only in warmer months. Also, the sand filter influent was weaker than characteristic household septic tank effluent. To fully understand the limits of hydraulic loading combinations with sand size, waste strength and temperature must also be taken into account. Despite these shortcomings, this study supports

TABLE 8
PEFORMANCE DATA

ADAPTED FROM: UC Davis study (8)
SYSTEM: ISF

REFERENCE:		1	2	3	4	5	6	7	8	9	11	12
DOSING (#doses/day)		4	24	24	24	24	4	12	24	24	4	12
HLR (gpd/ft^2)		1	2	8	16	4		4	4	4	4	4
Temp.	infl.											
deg.C	effl.											
COD	infl.	128	128	128	128	128	128	128	128	128	128	128
mg/l	effl.	26	11	0	8	7	0	10	13	13	37	12
TSS	infl.	32.7	32.7	32.7	32.7	32.7	32.7	32.7	32.7	32.7	32.7	32.7
mg/l	effl.	0.2	0.1	0.3	1.3	0.2	0.8	0.1	0.2	0.2	7.2	0.4
AMMONIA-N	infl.	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1
mg/l	effl.	0.03	0.05	0.02	0.07	0.04	0.05	0.05	0.07	0.05	0.68	0.05
NITRATE-N	infl.	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
mg/l	effl.	8	10.2	5.8	5.6	8.6	10.3	8.9	9.6	7.2	0.7	8
TKN	infl.	5.26	5.26	5.26	5.26	5.26	5.26	5.26	5.26	5.26	5.26	5.26
mg/l	effl.	0	0	0.3	0.35	0.1	0.22	0.15	0.3	0.26	1.22	0.32

current trends in design. Conversations with county health officials in states throughout the northern U.S. and Canada indicate that larger sand sizes are being employed with higher dosing frequency, with good results (19, 20). Reduced coliform removal is a concern, but has generally not been observed. The Davis study is often used as part of the scientific justification for this trend.

In a broader scope, this study demonstrates that ISFs can produce an effluent consistent with the previously-defined "anticipated performance" levels. Sand filters have also shown the ability to operate at higher hydraulic loading rates than have been historically used. This is strong evidence supporting current thinking that the use of larger sand sizes with increased dosing frequency can provide an increase in the hydraulic loading rate with less risk of failure and without compromising efficiency. This allows for smaller filters. The combination of higher loading rates and larger media sizes is also thought to be effective compensation for colder-climate applications (20).

Gloucester On-site Demonstration Project

The purpose of a current demonstration project in Gloucester, Massachusetts is to compare and contrast the effectiveness of different types of on-site systems (21). The study is funded by the U.S. EPA; it is part of the National On-Site Demonstration Project. One intermittent sand filter at a single-family residence is being monitored.

In the study's first year, a comprehensive set of parameters was evaluated (Table 9), and filter influent and effluent, upgradient wells were sampled. The monitoring of groundwater samples gives insight into the advection of treated wastewater discharged into soils. Temperature was monitored in this study and the first winter of data collection was

TABLE 9
PEFORMANCE DATA
ADAPTED FROM: Gloucester Onsite Demo. Project
SYSTEM: ISF

SYSTEM REFERENCE:		3 Month AVG., weekly sampling
DOSING (#doses/day)		
HLR (gpd/ft^2)		
Temp.	infl.	9
deg.C	effl	8
BOD5	infl.	278
mg/l	effl.	21
TSS	infl.	51
mg/l	effl.	6
AMMONIA-N	infl.	50
mg/l	effl.	54.3
	*up	3.6
	down	7.8
NITRATE-N	infl.	0.2
mg/l	effl.	2.4
	up	0.8
	down	0.9
TKN	infl.	66.3
mg/l	effl.	68
	up	4.4
	down	9.6
TOTAL N	infl.	66.5
mg/l	effl.	70.4
	up	5.2
	down	10.5
T.PHOSPHORUS	infl.	9.9
mg/l	effl.	6.8
	up	0.1
	down	0.5
T.COLIFORM	infl.	3.4E+05
org/100ml	effl.	3.3E+03

*up and down refer to up and down gradient groundwater sampling wells, approx. 25 yds from site

fairly cold. The duration of monitoring was three winter months, so effects of low temperature on the system's effectiveness are inherent. The system design was prescribed by Orenco, Inc., using their smallest filter (10 ft x 10 ft).

The performance of the ISF was slightly below anticipated levels, with BOD_5 removal of 92% and TSS removal of 88%. This may be due to the relatively high strength of the influent (278 mg/l BOD_5). With respect to nitrogen, there is a confusing picture. Both ammonia-N and nitrate-N are shown to increase slightly in sand filter effluent, which may indicate release of nitrogen into the wastewater by dying microbes in the septic tank. It appears that very little nitrogen conversion or removal took place. The lack of nitrification could very well be due to cold temperatures as the average sand filter effluent temperature was low (7.9° C). It might also be conjectured that the small size of the filter did not provide enough area and pore space for sufficient aeration for nitrification in these conditions. However, the project coordinator suspected a tightly compact soil covering the filter bed was suffocating the filter. A combination of the mentioned factors likely contributed to the inhibition of treatment.

This study had many of the ingredients necessary to draw conclusions about the expected performance of ISFs in Montana. The test utilized a high strength wastewater influent, there were cold temperatures during monitoring, and a complete set of data including well site sampling was generated. One important observation is that BOD_5 removal was less than anticipated during winter months, but still effective. The data also indicate that the nitrification process can be hindered if sufficient aeration is not provided. The exact cause of the hindrance could involve a number of factors including construction flaws, temperature, or possibly inadequate filter surface area. Limited nitrification was seen to

affect organic nitrogen in the soil profile. Most importantly, this study provides insight into the reality that the accepted values for sand filter performance can be compromised by variables such as climate, wastewater strength, construction practices and possibly design application. Nonetheless, the ability of intermittent sand filters to significantly improve septic tank effluent quality was demonstrated.

Anchorage, Alaska Monitoring Project

A current monitoring project in Anchorage, Alaska is being conducted by the municipality's Department of Health and Human Services (22). Emphasis is placed on effects of temperature and dosing upon ISF performance. In the available data (Table 10), four systems were monitored for a minimum of one year. All systems were Orenco designs with all of the cold weather adaptations, including air coils. Winter climate in Anchorage is similar to winter conditions in parts of Montana, but with more precipitation in the spring. Each filter was below a residential septic tank, so one can expect average strength wastewater although no influent data are given. Samples were taken at least once a month from each system.

During the study, the soil temperature never dropped below 35° F (1.67°C), while the air temperature dropped as low as -5° F. The temperature of the sand filter effluent never dropped below 41°F (5°C). The sand filter effluent was of excellent quality with respect to BOD_5 and TSS: both parameters were consistently below 10 mg/l in every system. Nitrification appears to have been relatively complete, as effluent TKN values were low. Monitoring of dosing frequency was extensive. These data support the recommended frequency of dosing, once every 30 minutes. This provided consistent rates of removal (22).

TABLE 10
PERFORMANCE DATA

ADAPTED FROM: Municipality of Anchorage
SYSTEM: ISF

REFERENCE:		A	B	C	D
HLR (gpd/ft^2)					
Temp.	*win	44	46		45
deg. F	*sum	55	53		53
BOD5	infl.				
mg/l	effl.	4.6	<.2	4	4
TSS	infl.				
mg/l	effl.	26.5	1.6	4	6.5
AMMONIA-N	infl.				
mg/l					
NITRATE-N	infl.				
mg/l	effl.	30.2	25	48	41
TKN	infl.				
mg/l	effl.				
TOTAL N	infl.				
mg/l	effl.				
T.PHOSPHORUS	infl.				
mg/l	effl.				
T.COLIFORM	infl.				
	effl.				
F.COLIFORM	infl.				
org/1ooml	effl.	2	511	11	1171

*sand filter effluent temperature; average of daily temps
win = October through April
sum = May through September

The level of nitrification during winter months remained relatively consistent with summer months. The cold climate adaptations may have been responsible for this consistency.

The overall performance of these ISFs appears to be excellent despite the winter cold. The cold climate design adaptations appear to have kept the systems functioning well throughout the winter months. However, one should note that these systems were carefully maintained by the party conducting the study. While there were no system failures, maintenance was required, including a pump replacement. Consistent monitoring of performance parameters and flow meters allowed the maintenance personnel to identify any potential failures and keep the system running effectively. This is, of course, not the case with many installations in the field. It can be concluded that with proper maintenance and care, a well-designed ISF can consistently operate at levels exceeding the standards set by the "baseline" studies. Another factor that may contribute to exceptional ISF performance is increased dosing frequency. It is commonly thought that increasing the frequency of dosing the warm septic tank effluent upon the filter maintains a higher level of microbial activity and treatment.

Placer County, California Study (23)

One of the most extensive studies of alternative on-site systems was undertaken in Placer County, California, in 1990. The study concluded in 1994 with comprehensive data for 44 newly installed ISFs at rural homesites located at elevations from 100 to 4000 feet. The purpose of the study was to accumulate data needed to judge the performance of ISFs before permitting widespread application of this technology. County personnel attributed their skepticism toward any type of secondary treatment to hasty acceptance in the 1970's of

"some proprietary package plants." The large numbers of failures required "lengthy institutional recovery time." A unique features of this study was the emphasis on gaining community acceptance of this technology. To do this, development of the study included all types of interested parties such as county supervisors, sewage system contractors, realtors, septic pumpers, equipment manufacturers, and others. The authors note that "impeccable scientific work can gather dust on a back shelf if the social aspects of regulatory systems are not properly addressed." They realized that if the community and regulatory agencies did not accept the validity of study, the potential of this technology would never be realized.

The ISFs were installed on rural homesites with marginal soils. The design of these systems mimiced that used in the 1982 Oregon Study. Some systems gravity-fed to the distribution field and some were dosed. The Northern California climate should be considered marginally cold, especially at the upper elevations, but temperature was not monitored in this study. With four years of monitoring, this study is certainly "long term." Also, to simulate actual situations, some systems were maintained more than others and some not at all. Influent and effluent data were taken. Overall, the study's approach can be seen as a rigorous evaluation.

The data show excellent system performance (Table 11). Septic tank effluent quality is seen to be consistent with expected values. COD removal was very effective. The TSS removal average is within what the baseline studies would predict, but occasionally elevated levels were seen. This is partially explained by the fact that septic tank screens were not always used. The data for the nitrogen show almost complete nitrification of ammonia-N with nitrate levels around 30 mg/l, which is as expected. Significant denitrification also

TABLE 11
PERFORMANCE DATA

ADAPTED FROM: Placer County, CA study (23)
System: ISF

REFERENCE:		AVG. of 30 SYSTEMS
HLR (gpd/ft^2)		1.23
Temp.	infl.	
deg. C	effl.	
COD	infl.	160.2
mg/l	effl.	2.17
TSS	infl.	72.9
mg/l	effl.	16.2
AMMONIA-N	infl.	47.8
mg/l	effl.	4.6
NITRATE-N	infl.	<.1
mg/l	effl.	31.1
TKN	infl.	61.8
mg/l	effl.	5.9
TOTAL N	infl.	61.8
mg/l	effl.	37.4
T.PHOSPHORUS	infl.	
mg/l	effl.	
F.COLIFORM	infl.	1.14E+05
col/100ml	effl.	1.11E+02
T.COLIFORM	infl.	6.8E+05
col/100ml	effl.	7.3E+02

occurred, reducing total nitrogen by 39%. Coliform removal was also effective as 99% of both TC and FC was removed. No measurements of phosphorus were taken.

The authors concluded that the ISFs were a success in that the data closely resembled expectations derived from the Oregon Study (15). They also pointed out experiences obtained from the "local learning curve." First, they recognized that sand filters are not "a panacea for all the ills of the poor quality and shallow soils in the County." They acknowledged that groundwater contamination may still result from the discharge of bacteria and nitrates if shallow groundwater exists. Finally they stated "the single most important, easily controllable factor which could improve the overall performance of a population of ISFs is simple routine preventative maintenance performed by knowledgeable expert personnel." The inference of this statement is that homeowners across a general population cannot be expected to provide the maintenance necessary to prevent system failures, and without routine maintenance by trained professionals, failures can be expected. The investigators also pointed out that properly placed risers and ports are essential to proper inspection and maintenance.

The Placer County study was a detailed look at the performance of a population of ISFs. Inherent in the data are the variable influent and maintenance conditions that true field conditions present. The conclusions reinforce notions that maintenance and monitoring of systems are critical to consistent performance. Also, when choosing an ISF one must take into consideration the effect of adding nitrates into the soil profile. Finally, the study shows that one of the biggest limiting factors to more widespread use of alternative on-site technologies is public acceptance. When public awareness of the technology is addressed, system implementation meets with less resistance.

Recirculating Sand Filters

There has been a surge of interest in RSFs, which are generally believed to have potential for enhanced performance over that of ISFs. Several recent studies have concentrated on addressing problems such as cold climate limitations and nitrogen removal.

RSFs in Montana

According to the survey that was part of this study (see Appendix), use of RSFs in Montana is very limited. The fact that an RSF is more dependent on pumps and timers generally leads to the conclusion that there is more potential for system failure, and the cost of the system will be excessive. These expectations are probably valid for residential use of RSFs. The level of organic and hydraulic loading seen in household effluent usually will not exceed the capabilities of an ISF. Also, the RSF may require more technical skill for maintenance than the average homeowner possesses (e.g. setting timers after a power failure). However, RSFs may be well suited for small commercial applications as RSF design characteristically can handle greater organic and hydraulic loadings. Also, arrangements for maintenance by qualified personnel are usually made with commercial applications. This is some of the reasoning behind Washington's recommendations for RSF applications in light commercial applications (19).

Cold Climate Studies at Michigan State University (13, 24)

One of the early concerns with recirculating sand filters was the effect of prolonged cold temperatures on the sand bed, which usually has a surface open to the environment. Ted Louden at Michigan State University has been assessing RSF use in cold climates since the

early 1980's. In 1984, Louden (13) built two open recirculating sand filters, one at a community college and one at a residence. Temperature was monitored for two winters. Data monitoring points included the septic tank outlet and several positions throughout the recirculation/filtration process. These systems were maintained several times a year; maintenance usually consisting of weeding and removing litter from the bed surface.

The data (Table 12) show that average temperature in the filter reached as low as 2°C. Recirculation tank temperatures dropped as low as 2.3°C, while monthly mean air temperatures for the winter of 1984 averaged below zero. Photographs of the filter during this bitterly cold winter show the bed almost completely frozen over, but areas around the effluent applicator heads remained unfrozen. A protective ice cone was built around each applicator, allowing infiltration. Some ponding did occur with each application, but wastewater infiltrated into the bed a few minutes after the pump shut off. Louden concludes that having successfully functioned through the winter of 1983-1984, these systems are likely to withstand any winter in Michigan. During winter, effluent BOD_5 and TSS were generally below 10 mg/l and fecal coliforms were generally less than 200/100ml. The nitrogen removal efficiency was probably the most significant finding; nitrogen reduction was 71-80% through the system. The investigator believes the total nitrogen reduction was brought about by effective nitrification (by the aerobic treatment in the open filter) and significant denitrification in the recirculation tank's anoxic atmosphere. Phosphorous removal was effective initially because the calcarous sand initiated calcium phosphate formation, but this process ceased as the calcium became unavailable. Concerning odors proliferating from the open bed system, Louden noted that three neighbors living within 200 ft. of the filter indicated they never noticed any odors.

TABLE 12
PERFORMANCE DATA

ADAPTED FROM: 1984 Michigan State U. Study (13)
System: RSF

REFERENCE:		Community College System
HLR gpd/ft^2		3
Temp.	air	-1.7
deg. C	recirc.tank	2.3
BOD5	infl.	150
mg/l	effl.	6
TSS	infl.	42
mg/l	effl.	2
AMMONIA-N	infl.	47
mg/l	effl.	2.1
NITRATE-N	infl.	0
mg/l	effl.	24
TKN	infl.	55
mg/l	effl.	2.3
TOTAL N	infl.	55
mg/l	effl.	26
T.PHOSPHORUS	infl.	16
mg/l	effl.	7
F.COLIFORM	infl.	3400
col/100ml	effl.	14

Data are 2-year average of weekly samples

In a paper presented in 1989, Louden summarized his 1984 work and reviewed other studies to provide recommendations for cold region application of RSFs (24). Some of the more important points are: (i) provide for a self-draining distribution system in the filter between doses, (ii) place the filter distribution system in a layer of round (not crushed) stone, (iii) the bottom of the filter media should be well below frost level, (iv) and less frequent dosing at night is recommended to conserve heat in the recirculation tank.

As of 1996, Dr. Loudon has been operating one RSF for nearly 14 years with the same sand and the same overall performance (25). He notes indications of anaerobic zones in the bed that may present a limit on loading rates in cold climates. Louden suggests a HLR limit of 3 or 4 gpd/ft^2. Additional suggestions include upward facing orifices with orifice caps. The importance of maintaining the laterals in the system by periodic flushing is also stressed.

Louden's work is a significant test of the recirculating filter's ability to withstand very cold temperatures. Equally important is the demonstrated ability of the RSF to promote denitrification, giving increased total nitrogen removal compared to the ISF. Louden suggested the more pressing issue concerning RSFs is soil absorption area reduction. This is currently being researched.

<u>Cold Climate Studies from Montreal, Quebec</u> (26)

Christiane Roy and Jean-Pierre Dube' recently examined the potential effectiveness of a recirculating gravel filter (RGF) in extremely cold temperatures. The premise was that a larger media size would reduce heat losses while maintaining efficiency (27).

Four full-scale filters were installed in-line with a research facility's septic system. Two different sizes of gravel were used (D_{10}= 2.5mm and 4.0 mm, and Cu< 2.5). The loading rate was 5 gpd/ft^2. The data collection period was from June 1993 to April 1994. Very rigorous temperature and influent monitoring was also carried out. Maintenance was routinely performed, but it was noted that the gravel did not allow plants to root, eliminating the weeding usually required.

A summary of the temperature data from the first phase of monitoring (two systems) reveals that the average low air temperature for January and February was around -25°C, with an absolute low of -38.5°C. However, septic tank liquid temperatures never dropped below 6°C. Heat losses in the noninsulated filter cells were seen to be greater than in the insulated cells, but neither system froze or failed. Throughout the seasons filter effluent BOD_5 and TSS values were constant, both well below 10 mg/l (Table 13). Nitrification in the system had the most fluctuation and Roy and Dube' concluded that the nitrification was clearly related to temperature. The least nitrification was during winter with the lowest nitrate values (as low as 3.8 mg/l) seen in April, two months after the lowest filter temperatures were recorded. These fluctuations in nitrification were not as pronounced in the Michigan studies. Total nitrogen removal efficiency was also lowered by this effect, but at 47%, it still exceeded the customary efficiency achieved by an ISF. The coliform removal was slightly lower than expected (97% instead of the usual 99%), but still effective, as effluent counts averaged 1.3E4 CFU/100ml. One would expect a reduced coliform removal from both the larger media size and the colder temperatures. Yet, the RGFs still performed at very satisfactory levels.

TABLE 13
PERFORMANCE DATA

ADAPTED FROM: Roy & Dube' (26)
System: RSF

REFERENCE:		1 YR. AVG., 1 SYSTEM
HLR gpd/ft^2		
Temp. (winter)	air	-25
deg. C	recirc.tank	6
BOD5	infl.*	101
mg/l	effl.	5.5
TSS	infl.	77
mg/l	effl.	3
AMMONIA-N	infl.	
mg/l	effl.	
NITRATE-N	infl.	<0.1
mg/l	effl.	12.2
TKN	infl.	37.7
mg/l	effl.	7.9
TOTAL N	infl.	37.7
mg/l	effl.	20.1
T.PHOSPHORUS	infl.	5.2
mg/l	effl.	3
F.COLIFORM	infl.	4.8E+05
CFU/100ml	effl.	1.3E+04

*infl. is septic tank effluent and effl. is sand filter effluent

The study indicated that a larger media size (gravel) is an effective cold weather design application. The RGF is very resilient to extreme cold temperatures and can generally perform at expected levels of performance for sand filters. Fluctuations in nitrification might be expected at extreme cold temperatures, but nitrification can occur year-round. Also, insulation over the filter cells is not recommended as it may inhibit aeration, but insulation of the septic tank and/or recirculation tank could reduce heat loss. As a result of this study, five small municipalities in Quebec were approved for RGFs.

Gloucester On-site Demonstration Project

This project in Gloucester, Massachusetts, is a comparative study between various types of on-site systems (21). Two recirculating sand filters are included in the study. The strengths of this study are that temperature is well monitored and a variety of sampling locations are included. The RSFs are connected in line to residential septic tanks.

The data shown (Table 14) are averages from a one year monitoring period. Temperature values were not recorded, but one can assume they would approximate those presented in Table 8. The data reflect expected effluent levels of BOD_5 and TSS. There did appear to be significant nitrification, since nitrate levels in the wastewater were raised almost 100% while total nitrogen removal was close to 50%. Fecal coliforms were also significantly decreased. Downgradient well samples show the ultimate effects of on-site wastewater disposal. Nitrates in downgradient well samples showed a significant rise from upgradient well samples, although a sample collected at the downgradient property boundary showed a very low nitrate concentration. This situation shows how a household might present

TABLE 14
PERFORMANCE DATA

ADAPTED FROM: Gloucester Onsite Demo. Project
System: RSF

SYSTEM REFERENCE:		A	B
HLR gpd/ft^2			
Temp.	infl.		
deg. C	effl.		
BOD5	infl.	314	270
mg/l	effl.	7	11
TSS	infl.	81	60
mg/l	effl.	12	15
AMMONIA-N	infl.	57.4	100.4
mg/l	effl.	17.5	19.9
NITRATE-N	infl.	0.5	3.5
mg/l	effl.	38	49.7
TKN	infl.	80.8	146.7
mg/l	effl.	21.9	26.7
	up		3.5
	down		20.3
	ypo		2.6
TOTAL N	infl.	81.3	150.2
mg/l	effl.	59.9	76.4
T. PHOSPHATE	infl.	7.1	15.8
mg/l	effl.	2.9	5
T.COLIFORM	infl.		
CFU/100ml	effl.		
F.COLIFORM	infl.	3.2E+05	9.1E+05
CPU/100ml	effl.	9462	6862
	up		22
	down	17	25

*up = upgradient well
down = downgradient well
ypo = yard pump out

a health hazard to its own groundwater supply from its on-site treatment, while still being in accordance with the regulations.

Like those reviewed above, this project demonstrated that the quality of effluent provided by the RSF is far superior to that provided by septic tank/leachfield treatment alone, with one exception. Recirculating filters raise the questions of whether the increased levels of nitrates in the system effluent are more desirable than the levels of organic and ammonia nitrogen in the septic tank effluent. Otherwise, the level of treatment provided by RSFs is in agreement with expected performance standards set by the "baseline" studies.

RSF Nitrogen Removal Studies in Wisconsin (28)

The potential for RSFs to provide total nitrogen removal has prompted several recent investigations. In a study reported in 1994, by University of Wisconsin students and staff successfully engineered total nitrogen removal rates of 70 and 60% with two RSF designs.

Two RSFs were installed at households where standard on-site treatment on sandy soil conditions had increased groundwater nitrate levels. The one-year study observed effects of temperature on the nitrification/denitrification processes throughout the system. System design utilized limestone storage to buffer the pH for the nitrification process in the sand filter (H^+ ions are generated in nitrification). Two different sand sizes (D_{10} = 1.4mm and 3" pea gravel) were used in the filter to obtain adequate retention time. Denitrification was achieved in the system by recirculating part of the nitrified sand filter effluent back into the septic tank to utilize the abundance of carbon and oxygen-poor conditions there. This concept is used in many new nitrogen removal designs with great success. The sand filter was a closed filter bed, but aeration was not seen to be a problem.

TABLE 15
PERFORMANCE DATA

ADAPTED FROM: Wisconsin RSF Study (28)
System: RSF

REFERENCE:		1 YR. AVG., 1 SYSTEM
HLR gpd/ft^2		
Temp. deg. C		
BOD5 mg/l	infl.*	270.6
	effl.	5.7
TSS mg/l	infl.	
	effl.	
AMMONIA-N mg/l	infl.	62.8
	effl.	7
NITRATE-N mg/l	infl.	<.2
	effl.	15.3
TKN mg/l	infl.	76.6
	effl.	8.1
TOTAL N mg/l	infl.	76.6
	effl.	23.4
T.PHOSPHORUS mg/l	infl.	9
	effl.	2.4

*infl. measurements are STE, taken prior to RSF being installed
effl. measurements are from filter effluent

Values for all performance parameters can be seen in Table 15. Temperatures were as low as 3.1°C in the RSF, with efficiency little affected. Nitrification was effective even at temperatures as low as 3.1°C in the filter bed, since effluent ammonia-N levels were never above 10 mg/l. Denitrification was also efficient: a 69% reduction in total nitrogen was seen even at temperatures as low as 4.1°C in the septic tank.

The authors concluded that RSFs can produce at least 60 - 70% total nitrogen removal with the use of their design and flow applications, despite Wisconsin's cold winters. This design may not be applicable where soft water conditions exist, because the added limestone necessitated frequent cleaning of precipitate-clogged laterals.

The implications of this study for Montana are evident. Coarse, transmissive soils are found in several areas of the state, and as suburbs grow nitrate contamination may be a concern. The simplicity of this design combined with its resilience to cold temperatures make good arguments for its application. However, the total nitrogen removal efficiencies are not as high as some newer nitrogen removal systems. If nitrate levels are of critical importance, other treatment options may be preferable.

Nitrogen Removal in RSFs: Tennessee Study (29)

Another recent study evaluating the potential for nitrogen reduction was conducted at the University of Tennessee at Knoxville. The objective of this study was to determine the influence of parameters such as septic tank effluent loading rate, recirculation ratio, and sand depth on the total nitrogen removal. One of the starting premises for the study was that maximum nitrogen removal is directly related to the recirculation ratio (max. efficiency = 1-(1/R) ; where R is the recirculation ratio). This equation says that if a recirculation ratio is

4:1, the maximum nitrogen removal efficiency is 75%, so a higher recirculation ratio will increase performance up to a point. Also, sand filter depth (and hence wastewater residence time within the filter) must be adequate to complete the nitrification process. The design of this RSF used the septic tank effluent as the carbon source, but added an anaerobic denitrifying chamber (DNC) in line with the sand filter and septic tank. The pilot system was put in line with a residential septic system. It included 12 different sub-units with varying sand depth and loading rates. The sand (or gravel) size used was 0.76cm.

To analyze the data, a mass balance approach was used to estimate nitrogen removal efficiency. This was broken down into parts: the efficiency of ammonia conversion by the sand filter ($E_{ammonia}$), the efficiency of the DNC to denitrify (E_{NOx}), and the combination of the two to remove all mineral nitrogen ($E_{mineral\ nitrogen}$). While no specific data were published in the paper reviewed, it was stated that removals "proceeded much as expected." The authors quantified the relationship among the depth of sand, wastewater loading rate, total mineral nitrogen removal as:

$E_{mineral\ nitrogen} = 3.0 + 5.31\ (SD) + 2.95\ (LR) - .26(SD)^2 - .03(LR)^2 + .08(SD)(LR)$, where SD is the sand depth (cm) and LR is the loading rate (cm/day). This predicts a maximum of 73% total removal efficiency. One important fact not highlighted with these results is that this is specific to a certain sand grain size, and specific to a particular wastewater strength. Verification of this relationship has not been reported for other systems.

This is the most specific quantification of the relationship between design parameters and performance seen to date. More importantly, it shows how one can estimate optimum design through a relatively easy experiment. Another important conclusion in this study is the evidence that maximum nitrogen removal efficiency occurs at much shallower sand depths

(18cm for nitrification and 5cm for denitrification) and higher loading rates (10 gpd/ft^2) than usually used. This study makes some generalizations by not qualifying the equations for design optimization. Factors such as climate, influent strength, and variability in filter media are neglected. However, if quantifiable relationships can be ascertained for a specific climate and available sand size, a design can be produced that should be able to operate with greater than 70% total nitrogen removal. This indicated great promise for the use of RSFs in nitrogen reduction applications.

EXPERIMENTAL TECHNOLOGY

Many new technologies are being explored with ISFs. Some of these applications show potential as viable on-site treatment options. While these types of systems are currently not allowable by Montana regulations, they may deserve some consideration in the future. Many of these systems are not sand filters at all but employ alternative media. However, they operate on the same principal: septic tank effluent is applied to a separate chamber where aerobic attached microbial growth degrades effluent constituents.

Crushed glass media (30)

One popular innovation is the use of crushed glass instead of sand for the filter media. There are benefits to using crushed glass. This is a way to recycle glass, and the media may be more cost effective than sand in some areas. In an experiment conducted by Stuth Co. of Maple Valley, Washington, the efficacy of crushed glass as a filter medium was evaluated. A crushed glass filter was installed parallel to a sand filter on a failing conventional system. Both filters received the same influent. The glass had a D_{10}= 0.24mm

and Cu = 7.8 compared to D_{10}=.27mm and Cu = 6.0 for the sand. This does not appear to be a great disparity, but in an infiltration test the sand showed a 95 sec/in infiltration rate while the glass showed a 9 sec/in rate (10 times as permeable). The decreased water retention capacity for the glass played a significant role in the comparative performances of the two systems. By state law, the filters could only be dosed a maximum of 4 doses/day. Taking into account the findings by Nor (8), increasing the dosing frequency could significantly dampen the difference in performance due to the disparity in water retention capacity. Nevertheless, the sand media only slightly out-performed the glass (Table 16). The glass provided very adequate treatment. There is enough evidence here to suggest that glass media may be an environmentally sound option for the future once the optimum design and loading parameters are established. The overriding economic limitation is site proximity to a crushed glass source, but increased collection of waste glass may make it more available.

<u>Bottom Ash Media</u> (32)

In the mid-1980s experiments were conducted utilizing bottom ash, a waste product of coal fired power plants, as a substitute for sand. The substitution occurred in places such as West Virginia where sand is scarce and bottom ash plentiful. This media holds particular promise for use in RSFs, since their effective media size is usually in the coarser range. Bottom ash was substituted for sand in a 1987 study undertaken by Swanson and Dix (32). The results were that the alternative media did not adversely affect the performance of the RSF: BOD_5 removal averaged 94%; TSS removal was 90% ;and TKN results showed 84% oxidation of reduced nitrogen (Table 17). Bottom ash is available in southeastern Montana

TABLE 16
PERFORMANCE DATA

ADAPTED FROM: Stuth Co. Glass Media Study (30)
System: ISF

SYSTEM REFERENCE:		GLASS*	SAND*
HLR gpd/ft^2		1.3	1.3
Temp.	infl.	16	16
deg. C	effl.	13	13
BOD5	infl.	183	183
mg/l	effl.	8.2	4.9
TSS	infl.	57.1	57.1
mg/l	effl.	5	2.5
OIL & GREASE	infl.	26.2	26.2
mg/l	effl.	2.6	3.4

*Average of one years' data, from monthly samples

TABLE 17
PERFORMANCE DATA

ADAPTED FROM: Bottom Ash RSF study (32)
System: RSF

SYSTEM REFERENCE:		Avg. Aug-Sept.	Avg. Oct.-Nov	Avg. Dec-Mar
HLR gpd/ft^2		3.7	5	3.8
Temp.	infl.			
deg. C	effl.			
BOD5	infl.	139	151	171
mg/l	effl.	8.7	6.5	11.9
TSS	infl.	86	70.3	68
mg/l	effl.	8.7	5.7	11
AMMONIA-N	infl.			
mg/l	effl.			
NITRATE-N	infl.			
mg/l	effl.			
TKN	infl.	63.7	56.7	41
mg/l	effl.	13	5.8	8.6

and may provide a less-expensive alternative to sand. This will depend upon site proximity to the media source. Investigations at the local level are necessary.

Waterloo Biofilter (67)

Prefabricated synthetic materials are common substitutes for sand in intermittent filters where the surface area to volume ratio is to be increased. The particular media tested by researchers Jowett and McMaster (67) is unique in that it is absorbent. The media is said to allow for separate pathways through the media for air and water. This allows simultaneous hydraulic loading and ventilation resulting in effective treatment of wastewater applied at higher loading rates. Loading rates of 12.3 - 19.6 gpd/ft^2 have been used (compared to .5 - 2 gpd/ft^2 commonly used with sand filters). Data from a years' worth of monitoring at temperatures ranging from 5 - 14° C is seen in Table 18. The filter has been developed in Canada making cold climate influence inherent in the data. The results show excellent treatment at high loading rates. This alternative media has received widespread attention. It will be increasingly prevalent in on-site applications, and should lend itself well to application in Montana.

Lateral Flow Sand Filters (31)

A slight variation on the traditional ISF design is the lateral flow sand filter used exclusively in Nova Scotia. The design incorporates a sloped bed in which treatment takes place as the influent moves down the 5% slope of the bed laterally, instead of vertically. The effect is that the effluent flows through several linear meters of media versus 24-36 inches in

TABLE 18
PERFORMANCE DATA

ADAPTED FROM: Waterloo Biofilter (67)
System: Biofilter

REFERENCE:		1 YR. AVG., 1 SYSTEM
HLRgpd/ft^2		
Temp.	infl.	
deg. C	effl.	
BOD5	infl.	137.7
mg/l	effl.	2.4
TSS	infl.	83.1
mg/l	effl.	2.5
AMMONIA-N	infl.	11.4
mg/l	effl.	2.2
NITRATE-N	infl.	0.26
mg/l	effl.	18.8
TKN	infl.	
mg/l	effl.	
TOTAL N	infl.	
mg/l	effl.	
T.PHOSPHATE	infl.	
mg/l	effl.	
T.COLIFORM	infl.	1.5E+07
CFU/100ml	effl.	4.2E+04
F.COLIFORM	infl.	
CPU/100ml	effl.	

TABLE 19
PERFORMANCE DATA

ADAPTED FROM: Nova Scotia Lateral Flow System (31)
System: ISF

REFERENCE:		1A	1B	2A	2B	3A	3B
HLR gpd/ft^2		0.8	0.8	0.8	0.8	0.8	0.8
Temp.	infl.						
deg. C	effl.						
BOD5	infl.	216	216	216	216	216	216
mg/l	effl.	<2	2.1	<2	<2	2.1	<2
TSS	infl.	146.7	146.7	146.7	146.7	146.7	146.7
mg/l	effl.	0.8	17	1.2	103	0.9	109
AMMONIA-N	infl.	69.2	69.2	69.2	69.2	69.2	69.2
mg/l	effl.	0.07	0.07	0.07	<.05	<.05	<.05
NITRATE-N	infl.	<.05	<.05	<.05	<.05	<.05	<.05
mg/l	effl.	73.2	71.7	64.7	71.3	65.3	71.7
TKN	infl.	96	96	96	96	96	96
mg/l	effl.	0.9	1	0.7	1	0.6	1.1
TOTAL N	infl.						
mg/l	effl.						
ORTHOPHOS.	infl.	12.2	12.2	12.2	12.2	12.2	12.2
mg/l	effl.	7.3	10	0	0.5	0.3	4.8
T.COLIFORM	infl.	6.2E+06	6.2E+06	6.2E+06	6.2E+06	6.2E+06	6.2E+06
CFU/100ml	effl.	0.0E+00	46.7 0	16.7 0	113		
F.COLIFORM	infl.	2.5E+06	2.5E+06	2.5E+06	2.5E+06	2.5E+06	2.5E+06
CFU/100ml	effl.	0	0	0	0	0	0

a vertical flow system. Performance of three pilot models used in the development of this design was very similar to that seen in previously-reviewed studies (Table 19). One advantage of this design is that it allows use of larger sand sizes while still maintaining an adequate detention/treatment time for the waste stream (20). The faster rate of travel of influent through the filter decreases the possibility of ponding from clogging or freezing. This design offers no incentives in terms of cutting construction cost (the same amount of media is used as in vertical flow designs) or increased performance; its advantage instead is in combating the complication of freezing.

RAMIFICATIONS FOR MONTANA

This section is a review of the primary findings or "lessons" conveyed by the sand filter projects and literature reviewed. Some of the conclusions may appear to be sweeping generalizations considering the limited evidence presented here. They are the result of the cumulative experience of researchers involved in this study. Telephone conversations with county and state health/environmental officials, and private contractors, as well as literature from other studies support these conclusions.

One of the main objectives of this study is learn whether recent monitoring of sand filters in cold climates agrees with general assumptions about sand filter performance. The data reviewed reveal that **in general**, sand filters can be expected to perform within the "expected performance parameter" levels almost entirely developed in warmer places. However, within a **population** of filters, operating trouble or failures can be expected to occur. The lifestyles of individual families differ such that "average household" influent as

well as proper maintenance and care cannot always be expected. With **consistent** monitoring of even simple parameters such as pH or dissolved oxygen, problems such as groundwater infiltration to a leaky septic tank can be detected. The subsequent hydraulic overloading of the sand filter can then be averted. The homeowner can potentially save money in the long term and avert health risks with a maintenance and monitoring plan. Many counties in Washington, Oregon, and California have programs requiring the alternative on-site system owner to have a maintenance and monitoring contract with a licensed professional. This became necessary as systems failed in environmentally sensitive areas. As Montana's population continues to grow, a requirement for on-site system monitoring contracts in environmentally sensitive areas may be a valid consideration.

Another primary objective of this study is to evaluate the effect of cold temperatures on the on-site systems. Temperature is seen to play a minor role as septic tank temperatures tend to stay above 5°C, even in extremely cold climates. Increasing the frequency of doses applied to the filter decreases the possibility of freezing and ponding in the filter. The breakdown of organic material is relatively unaffected at winter temperatures. However, nitrogen removal processes such as nitrification can be adversely affected by the cold. Nitrification is seen to be effective at filter temperatures even slightly below 5°C. The efficiency of the nitrification process can be aided by cold climate design adaptations. The denitrification process is more adversely affected at lower temperatures. To maintain denitrification efficiency may require more heat-saving adaptations than are applicable to ISFs and RSFs. If removing nitrogen is critical, the installation of a specialized nitrogen removal system may be a better solution. The use of timed dosing systems and increased dosing frequency is perhaps the most effective means of diminishing the negative effects of

cold temperatures. Cold climate design adaptations such as insulated covers and air coils also aid in obtaining consistent performance in cold climates.

BOD and TSS removal is seen to be very consistent in mature, well-maintained sand filters. Sand filters are not very sensitive to increased hydraulic and organic loading rates. Research has shown that filter size can be significantly reduced and HLRs increased without compromising the effluent quality with respect to these two parameters (8, 16).

The issue of nitrogen removal in sand filters is both complex and controversial. Many advocates of sand filters boast 50% nitrogen removal in ISFs; in fact, ISFs consistently provide less than 50% Total N removal (15, 21, 23). Thirty percent total nitrogen removal is a more realistic estimation of ISF nitrogen removal capacity. RSFs are sometimes able to provide 50% or greater nitrogen removal, but temperature and operational parameters such as dosing rate and frequency affect this (13, 26). Study results often do not include enough parameters to calculate a mass balance for nitrogen. What is usually presented is enough data to show the conversion of ammonia-N to nitrate-N (nitrification). In sand filters this conversion is almost always complete, evidence of the aerobic nature of the system. However, nitrogen removal requires the further conversion of nitrate-N to N_2 gas by denitrification. Traditional ISF and RSF designs are not engineered to maximize denitrification efficiency. Nitrification without denitrification could be considered detrimental since nitrates are more mobile in the soil profile than the ammonia discharged in septic tank effluent. Sand filters have the potential to elevate groundwater nitrates, but whether this poses a health concern is a site specific condition.

It is also necessary to review the design trends for sand filters. Increased demand has led to a form of commercial packaging of these systems. In the past, design manuals from

both public and private sources contained "cookbook" recipes for constructing sand filters. There was little consideration for variables such as influent strength and climate. Currently there is a trend towards a more engineered approach to sand filter application.

For ISFs, several aspects of design and maintenance are being tested. Probably the most common recommendation in recent literature is the use of "maintenance friendly" designs, incorporating more access to system laterals and other subsurface installations. Some states are incorporating these applications into their rules (19). Certain cold climate applications that are currently being incorporated, such as air coils and insulation, can improve performance, especially with respect to nitrification. ISFs are currently being downsized to reduce land and material costs. However, one must take precautions to insure ample oxygen will be available to the filter when using such designs. Another current trend is the use of larger media sizes with smaller but more frequent dosing. This is believed to reduce both maintenance frequency and the potential for system failure. A change in current Montana rules would be necessary to implement this criterion, as WQB-5 allows a maximum of only 4 doses per day. More frequent dosing would wear out dosing pumps more quickly, which is the main reason for the reluctance to adopt this approach. Other design recommendations are: (i) the use of smaller-diameter laterals to increase scouring and reduce clogging and (ii) the use of pump screens to reduce clogging.

It has been shown that recirculating sand filters are very resilient to cold weather. These designs can be optimized using larger media sizes than are currently recommended. Media as large as pea gravel may be used in very cold climates to reduce heat loss and maintenance requirements. The increased sophistication of recirculating filters over intermittent filters does not appear to be a detriment to their reliability. The fact that RSFs

provide increased total nitrogen removal may warrant an increase in their use, especially in light commercial applications.

RECOMMENDATIONS FOR FURTHER STUDY

An immediate concern that needs to be addressed is the influence of sand filters upon the groundwater concentrations of nitrate. Nitrates are highly mobile in the soil profile, and contamination of groundwater is linked to medical problems such as miscarriages (60). The number of sand filters in certain communities in Montana is concentrated enough that the effects of discharging elevated concentrations of nitrates into the soil profile can be evaluated. Determining if this is an immediate health concern would be an even larger task, but may be necessary in the future.

Another area for further research may be the use of recirculating sand filters in applications involving larger hydraulic/organic loading and light commercial applications. The limits of organic loading on RSFs are still questionable. Are they effective treatment for organic matter, especially oil and grease, in restaurant wastewaters? More data are needed to answer this question.

Also of interest is the use of alternative media, such as glass or bottom ash which have shown promising results. As their operating record becomes more established, their use may hold economic as well as environmental advantages in some areas of the state.

ELEVATED SAND MOUNDS

Elevated sand mounds are absorption systems in which septic tank effluent is distributed through laterals atop an artificial mound of clean sand (Figure 3). Mounds were introduced in the 1950s as an attempt to overcome site conditions prohibiting conventional subsurface soil absorption (33). The first systems were developed in North Dakota (NoDak mounds), but research with sand mounds was continued primarily at the University of Wisconsin-Madison. Since the late 1970s the Wisconsin mound design has been the standard. The Small Scale Waste Management Project at the University of Wisconsin-Madison has compiled an extensive library based on its research with mounds. The Wisconsin group's work with mounds has been so complete that few have deviated from its design. Certain areas of the U.S. and Canada have many sand mounds. In the review that follows, current design directives are first examined, to identify any differences among sources. Next, what has been traditionally accepted as the expected performance level of mounds is examined. Accepted performance is then compared to current research to examine the mound system's long-term reliability. Finally, the applicability of these systems for use in Montana is assessed.

Performance data from sand mound systems are seldom published. Nutrient, coliform, and organic carbon removal are only occasionally monitored. The concept of performance is based on whether or not significant surfacing effluent is present (to be consistent with the literature, this chapter uses the term "failure" to denote consistently ponding effluent). There are several possible reasons for the lack of data. Sand mound systems serve as both treatment and disposal (considering the sub-mound soil as part of the system). This makes sample

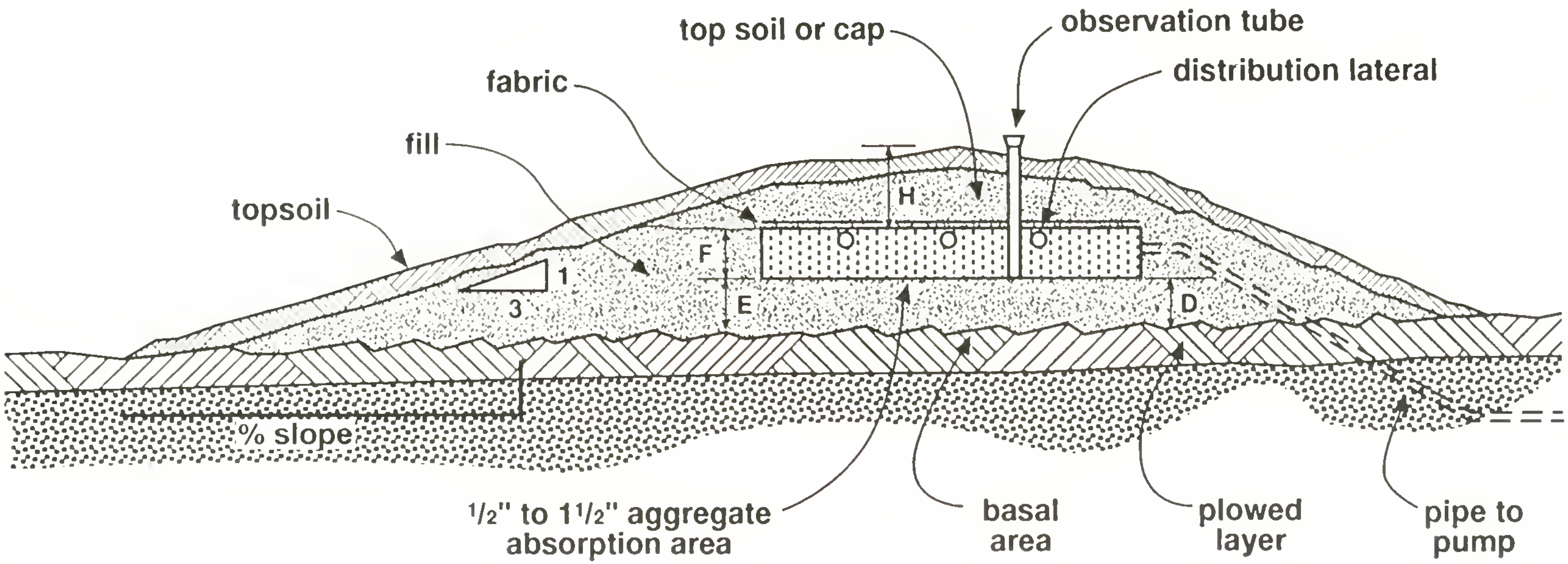

Figure 3. Wisconsin Mound Cross-section (33)

collection difficult. Also, it is often assumed that the larger volume of sand (compared to sand filters) and the larger surface area to which the effluent is applied in mound systems, assure that treatment will be sufficient. Hence, the primary questions that have traditionally been raised about mound systems have been about their reliability and not about the level of effluent treatment. Also, the primary researchers in this field, Tyler and Converse, have focused most of their research on the mound's applicability on varying site and soil conditions.

DESIGN CRITERIA

The most current and widely used information related to mound design is published by the Wisconsin Small Scale Waste Management Project. Other design manuals are compared to its directives in this review. There are not as many design directives for mounds as for sand filters, and most contain the same basic equations for determining mound dimensions such as basal area, absorption area, and interior depths. Some basic operating parameters are compared in Table 20, as these are what will often determine the success or failure of the system. Other design details such as equations for determining mound dimensions, lateral diameters, perforation spacing, etc., can be found in the referenced texts.

University of Wisconsin; Small Scale Waste Management Project (33)

Mound design is dictated by the site soil conditions. Designs are based on varying conditions such as depth to limiting soil condition, site slope, loading rates, and even climate. The original Wisconsin design was developed for individual homes with specific site and soil limitations, but designs have been adapted to accommodate a variety of conditions.

TABLE 20

ELEVATED SAND MOUND DESIGN SPECIFICATIONS

DIRECTIVE	HLR	OLR	MEDIA SIZE	OTHER RECOMMENDATIONS
1980 EPA Design Manual	1.2 gpd/ft^2	ng	ng	
WQB5	1.2 gpd/ft^2	ng	.05 mm < D50 < .1mm	48' to limiting condition; perc. rate > 120 min./in.
Washington Guidelines	1.2 gpd/ft^2	ng	ASTM C-33	18" to limiting condition plow soil surface
U. Wisconsin	1.0 gpd/ft^2	dependent on HLR	ASTM C-33	many, see text

ng = none given

These recommended soil and site criteria are based on Wisconsin's research and experience (adapted from 33):

Parameter	Values
Depth to High Water Table	10 in. minimum
Depth to Crevice Bedrock	2 ft. minimum
Depth to Non-crevice Bedrock	1 ft. minimum
Permeability of top 10 in.	moderately low
Site Slope	25% maximum
Filled site ?	ok
Over old system ?	ok
Flood plains ?	no

The authors caution that these are more liberal values than were historically used, and designer/contractor experience is crucial as site conditions approach these limits. Proper methods to accurately determine these site conditions are also critical, but are beyond the scope of this study. Montana's regulations are less specific and more restrictive than these: a 48 in. depth to the limiting soil condition is required.

The general recommended dimensions produce a long and narrow mound. The interior mound sections are seen in Figure 1. Details for determining depths of sections such as D, H, E, etc., can be found in the reference. The recommended hydraulic loading rate of 1.0 gpd/ft^2 is a revision of the authors' earlier work, which recommended 1.2 gpd/ft^2.

Montana Circular WQB-5 (1)

Montana's equations for determining bed areas and depths are in agreement with the University of Wisconsin's and those of other texts. However, Montana has some prerequisite site conditions that are not seen in other directives. Montana's regulations state that "elevated sand mounds shall not be utilized on soils where the high groundwater level, bedrock or other strata having a percolation rate slower than 120 minutes per inch occurs within 48 inches of natural grade or where rapid percolation may result in contamination of water-bearing formations or surface waters." Montana's requirement might be expected to limit mound use, but mounds are used relatively frequently throughout the state (see Appendix).

EPA 1980 Manual (3)

The EPA manual adopts the University of Wisconsin's method for calculating interior mound section depths and basal area. The principal difference is the recommendation of 1.2 gpd/ft^2 for the loading rate vs. 1.0 gpd/ft^2 in the current University of Wisconsin manual. The net result is that the Wisconsin design has larger dimensions and subsequently more surface area for treatment.

Washington State (34)

Washington has more explicit guidelines for mound construction than Montana. Siting requirements only call for 18" of unsaturated soil above the limiting soil condition. Some of Washington's construction guidelines are unique. For example, they recommend plowing the soil interface area beneath the mound, while other directives recommend leaving it alone.

Conclusions on Design Directives:

All directives agree on the general height and depth dimensions for mound construction. While the equations for determining these dimensions are presented in different forms, they all produce the same sized mound for given input specifications. The most significant difference between the current University of Wisconsin design and the other guidelines reviewed is Wisconsin's use of 1.0 gpd/ft^2 hydraulic loading rate versus 1.2 gpd/ft^2 seen in others. While this appears to be a small difference, this figure is critical when making other design calculations. For example, when sizing the absorption area (sometimes called the infiltrative surface area) the use of 1.2 gpd/ft^2 will result in a 17% smaller infiltrative surface area. This added area could be the difference in a mound system failing or not.

Each directive has different but useful construction tips. Despite the simplicity of the directives, the complexity of the system should not be underestimated. Cooperation and full understanding of the system by site evaluator, contractor and designer are critical for proper installation. Conversations with state officials and private consultants, and the results of the survey (Appendix) indicated that cooperation is <u>the most important factor</u> in the success of a sand mound system (19, 35). If the contractor does not understand the basic principals of system operation, shortcuts such as using inferior fill materials or excessive use of machinery can result in the failure of even the best design. Also, poor methodology in determining the native soil type and infiltration rate or depth to high groundwater by the site evaluator will result in system failure.

ESTABLISHED PERFORMANCE EXPECTATIONS

Several of the earlier definitive studies on sand mound performance are reviewed below. These studies are often cited in the literature when referring to the quality of effluent provided by an elevated sand mound system.

Water Resources Center (U. of Wisconsin-Madison) 1979 Mound Evaluation (36)

This comprehensive study from Wisconsin is one of the few studies that lists numerical data for performance parameters. Nutrient removal, bacterial attenuation, temperature, and dosing effects were the main foci of this study. Twenty-six previously-installed systems were randomly selected out of 260 mound systems in operation in Wisconsin at the time. The systems were divided into 4 groups according to their loading rates and sand uniformity coefficients. A bimonthly sample was taken from each system from Februrary, 1977 until August 1978. Groundwater wells and septic tank effluent were also monitored.

From the temperature monitoring, cold weather was seen to have an effect on a few of the systems as water ponded in two systems when the bed temperature dropped as low as 2° C. Measures such as insulated covers over pump chambers and proper insulating cover (landscaping) on the mound were said by the authors to be effective at preventing effluent surfacing.

Table 21 shows the efficiency with respect to basic performance parameters. BOD and TSS were not measured in effluent because the post-treatment sampling was in unsaturated soil. The nitrogen transformation presented a complicated picture as various systems vacillated between anaerobic and aerobic conditions depending on dosing rate, sand

TABLE 21
PERFORMANCE DATA

ADAPTED FROM: 1979 Wisconson Mound Study (36)
System: Mound

REFERENCE:		A	B	C	D	E	Mean of 260
HLR gpd/ft^2		0.51	0.25	1.16	0.37	0.12	
Temp. deg. C	infl.						12.7
BOD5 mg/l	infl.						103.2
TSS mg/l	infl.						78.9
AMMONIA-N	infl.						45.3
g^-6/g (dry soil)	5 cm*	8.21	7.14	2.7	1.9	1.4	0.69
NITRATE-N	infl.						0.008
mg/l	5 cm	1.64	1.97	0.46	0.21	3.2	1.23
TKN	infl.						69.9
g^-6/g (dry soil)	5 cm	235.5	383.7	945.9	682	697.1	306.3
TOTAL N	infl.						
mg/l	5 cm						
T. PHOSPHATE	infl.						19.83
g^-6/g (dry soil)	5 cm	87.8-		51.1	159.9	101.5	69.4
T.COLIFORM	infl.						2.1E+06
mpn/100ml	5 cm	5.1E+03	1.40E+05	1.40E+03	1.25E+04-		4.80E+03
F.COLIFORM	infl.						6.1E+05
mpn/100ml	5 cm	140	1.40E+05	5200	100-		520

*samples taken at 5 cm soil depth surrounding mound systems

uniformity, and depth in the media. The most significant result is that the group of mounds with the lowest dosing rates and most uniform sand had the most efficient total nitrogen removal. Nitrification occurred in the upper portions of the sand fill with almost complete nitrification of ammonia-N. Denitrification occurred just above or at the sand/soil interface, removing 60% of the nitrate-N concentrations. The highest total phosphorus levels were measured at 15 cm into the soil, and phosphorus decreasing significantly with soil depth. No removal of orthophosphates was seen in the sand fill before it reached soils underneath the mound. Thus, the efficiency of mounds to reduce phosphorus is dependent upon the soil type below the sand fill.

The efficiency of bacterial removal was linked to dosing rate. The lower the dosing rate, the better the efficiency, but on average systems provided a high quality effluent with fecal counts averaging 877 MPN/100ml at a 5cm soil depth.

The results of the groundwater monitoring revealed that a properly functioning system generally reduced fecal coliform, nitrate-N and phosphorus to near background levels. However, a failing mound was found to deposit significant levels of nitrate-N (40 mg/l) in groundwater samples taken close to the seepage, as only the nitrification process has occurred in the upper regions of the mound. However, nitrate levels were significantly reduced as close as 10 feet away from seepage. Nitrate-N concentrations in groundwater samples taken 100 feet away from the system were down to 15 mg/l . This measurement is, of course, very specific to the site's soil characteristics.

Hydraulic failure of two systems occurred in the study population, and both systems were built by the same contractor. The fill media was a loamy sand that was dosed at a rate recommended for a medium sand.

The above-mentioned failures are reflective of the authors' final comments that the most important factor in sand mound performance is contractor knowledge. They also concluded that most mound systems were being incorrectly dosed, with excessive dose volume and not enough frequency.

This study was one of the first to present data for performance parameters for mound systems in the field. The focus was more on the "where" and "how" of nutrient and bacterial removal, rather than determining maximum efficiency levels. Yet, it does provide proof that a properly functioning mound provides high quality effluent despite soil limitations at a site. Also, the recommendations about cold weather applications and dosing were significant design improvements at the time.

<u>Wisconsin Mound Performance 1986</u> (37)

This study by Converse and Tyler was a retrospective look at the efforts of the state of Wisconsin to educate installers and designers about mound application, and to identify any technical problems. By 1986 there were 7000-9000 mounds in Wisconsin, a majority of which were replacing failed conventional systems. Systems were randomly selected and surveyed for several designated symptoms indicative of failure. The study equated performance with disposal, and collected no performance data. The study's survey was done in three parts, in 1981, 1983 and 1984.

The symptoms for which the systems were surveyed were (i) ponding in absorption area, (ii) side seepage, (iii) spongy side, (iv) toe leakage, (v) spongy toe, (vi) excessive flow back into dose chamber after pump event and (vii) little effluent removal from dose chamber during pumping event. Suspected causes of these symptoms were also given. The conclusions

from each of the three phases were compared to similar county and state surveys. The results were consistent throughout the state and showed that, overall, the mounds were performing very well. On a consistent basis, 99% of the mounds did not have any toe leakage, 98.5% did not have any side seepage, and 97% did not have soft or spongy areas, and less than 3% had any serious hydraulic problems. However, the authors concluded that ponding chances may increase with system age, and seasonal or intermittent ponding is common. It is also noteworthy that on average these mounds were being loaded at less than 50% of their design hydraulic capacity. If the systems were loaded near design capacity more ponding and seepage could be expected.

This study is illustrative of the approach that good performance is directly indicated by lack of surfacing effluent. The study demonstrated that properly installed and operated mounds operate very reliably. One of the more important findings was that occasional ponding is common. The bigger question is "is this a potential health hazard?"

Converse and Tyler addressed this question earlier in their studies. In a 1984 study (38) they sampled effluent from the leaking toe of several systems for coliforms. In all but one case they found fecal coliform counts to be less than 10 CFU/100ml. The authors found this to be consistent with earlier studies (Harkin, et al. 1979 and Bouma et al. 1973) that also reported excellent coliform attenuation by the mound prior to any native soil infiltration. This would suggest that a slowly leaking or spongy mound does not present a health hazard, and this is part of the normal operation of a mound.

1982 Oregon Final Report (15)

As mentioned, the Oregon Report was one of the first and most influential long-term studies on on-site wastewater treatment systems. Mounds were among the systems included in the study. The evaluation consisted of monitoring three mounds located in an area of poorly drained soils. Medium and fine sands were used, and fill depths were increased to provide insurance against high groundwater during Oregon's rainy season. Mounds were constructed with advice from the University of Wisconsin's top researchers.

Monitoring wells were placed in each mound and at up and downgradient sites. Goundwater infiltration and wasewater dilution were very prominent with some systems, making sampling and interpreting results difficult. Also, data for performance parameters were collected from only one system. Ponding was evident for some systems, usually a few feet from the toe.

The Oregonians concluded that the precipitation in high-rainfall seasons presented major operational difficulties for mound systems. As a result, no mounds were permitted in Oregon's experimental program after 1977. Some additional reasons cited for this were: (i) excessive sand cost, (ii) general shallowness of soils to seasonal groundwater (less than 24 in.), (iii) and extensive field testing already underway in Wisconsin.

CURRENT RESEARCH AND MONITORING

While there are numerous papers and individual monitoring projects involving elevated sand mounds, those reviewed here are often-cited studies that should provide some insight into sand mound applications in Montana.

Monitoring of Sites in Montana

Mound systems are very prevalent in many Montana counties, but available data for performance are scarce. The available data are from occasional grab samples. The monitoring reports only a few parameters and does not report potential problems such as ponding or spongy areas. The sampling reports reviewed in this study did show low total and fecal coliform counts, as well as low nitrates and phosphorus in groundwater monitoring wells near the systems. While there no indication of with poor effluent quality in the monitoring data, occasional ponding effluent from mound systems has led to their characterization by some officials as "temperamental".

Nitrogen and Fecal Coliform Removal in Wisconsin Mound Systems (39)

This work reported in 1994 by Converse and Tyler. Thirteen mound sites in Wisconsin were evaluated for their effectiveness reducing coliforms and nitrogen. Great attention was paid to soil conditions beneath the mounds to draw conclusions as to the effect of varying soil types on treatment. The mound fill averaged 19 in deep and was medium to coarse sand.

This study included extensive monitoring of coliforms and nitrogen species the three parameters throughout the mound and soil profile. The reduction of fecal coliforms was found to be effective. The mound systems were efficient at nitrifying septic tank effluent, but denitrification was marginal. Nitrate concentrations in the soil profile beyond the influence of the mound system (3 ft. deep) averaged 34 mg/l. The authors noted that this exceeded the drinking water standard (10 mg/l) by 3.5 times.

This study showed that sand mounds are effective at bacterial remediation. However, unlike the 1979 Wisconsin mound performance evaluation, little denitrification was observed. This may be due to the use of more uniform coarse sand material, which did not allow prolonged saturation (and development of anoxic conditions) within the lower portion of the mound. The authors noted that the deposition of the highly nitrified effluent into the soil profile may present a health concern as it is well above the drinking water standards.

Mound Performance Studies in Maryland (40)

The state of Maryland recently conducted a performance review of 36 sand mounds in that state. The focus of the study was mound performance on slowly permeable soils. No data for performance parameters were recorded. Ponding, seepage, and moist areas were surveyed.

The mound systems exhibited reliable performance overall, although 25% exhibited occasional seepage, and 56% had moist areas.

The authors cited several possible reasons for the mounds' erratic behavior. They noted that the slowly permeable soils compounded any potential problem such as high groundwater. Owner abuse contributed to some problems, such as rutting the mound with a lawnmower. The variable that had the largest correlation to mound performancewas said to be the system siting.

The investigators considered the mounds' performance successful, despite the number of systems that exhibited surfacing effluent. This is further evidence that occasional seepage is to be expected. The importance of contractor/designer/site evaluator cooperation is again

stressed. Maryland attributes part of the success of these systems to state-sponsored workshops on mound construction.

RAMIFICATIONS FOR MONTANA

In the performance of this review, communications with professionals having experience with mounds, and not empirical test results, have been the major sources of information. A common trend revealed is that professionals in areas where mound installations are not numerous have expressed the most dissatisfaction with their performance (see Appendix). This strongly supports what is commonly noted in the literature, that experience in all phases of design, siting and construction is the largest contributing factor to successful mound performance. Poor performance should therefore be addressed at the state and local level, with training seminars and workshops in areas where this technology is relatively new. This approach is already adopted in several states and time will tell if it is effective.

Most of the research on sand mounds has been conducted in Wisconsin and North Dakota, making the effect of low temperature on performance inherent in the results. Cold temperatures appear to affect performance only if there are shortcomings in the system design or installation. Researchers have not observed problems with performance in cold weather on the part of properly implemented systems.

While there is little BOD or TSS monitoring, the data for other parameters such as fecal coliforms suggest that BOD and TSS are effectively removed. The earlier baseline studies as well as current research indicate that mound systems provide exceptional secondary treatment of septic tank effluent for coliforms. With regard to the nitrogen treatment, there

appears to be a "catch 22." Design evolution of mound systems has led towards more coarse sand sizes being used to circumvent the problem of occasional ponding. The increased infiltration rate does not allow saturated conditions to develop, limiting the denitrification process in the mound. The result is the deposit of higher nitrate concentrations in the soil profile and possibly groundwater. This problem is also seen with sand filter designs.

Mound systems are seen to be very sensitive to operating parameters, mainly the hydraulic loading rate. There is evidence to suggest that the accepted rate of 1.2 gpd/ft^2 may be excessive.

While these systems have been labeled "temperamental" by some professionals in this field, troubleshooting and system remediation can often be simply handled. This also has been an area of research for Converse and Tyler and they have published some very practical advise for maintenance and troubleshooting these systems (41).

Finally, many states are observing a decline in the use of mound systems, based upon cost considerations. The cost of producing a media with the desired particle size and uniformity, as well as hauling costs, have been cited as reasons for choosing other alternative system types.

RECOMMENDATIONS FOR FURTHER STUDY

As with sand filters, there appears to have been little research into the effects of high organic loading on mound systems. It is occasionally said to be an unimportant consideration (36), but conversations with professionals in the field often point to organic overloading as a possible cause of failure. Some experiments with a lower loading rates but very high influent strength might help define the influence of this parameter.

EVAPOTRANSPIRATION SYSTEMS

Evapotranspiration (ET) systems are large sand beds, at grade, that receive septic tank effluent for further treatment and discharge (Figure 4). These systems rely on evaporation and plant uptake of wastewater (transpiration), and do not discharge wastewater to the subsurface. Evapotranspiration-absorption (ETA) beds are unlined, and do discharge to the subsurface. ET and ETA systems are used where site limitations preclude more than a small amount of discharge.

One of the earliest investigations into evapotranspiration as a means of wastewater disposal came from Dr. A.P. Bernhardt at the University of Toronto (42, p.17). He developed equations to quantify the evaporation rate from shallow subsurface drainfields, and discovered significant amounts of fluid could be removed by evapotranspiration. His ideas were developed into the first ET designs in the 1960's. These systems came into popularity in the 1970's in many areas, particularly the southwest. There are also many ETA systems in use in cooler climates such as Canada, Colorado, and Montana. Recently, research into these systems has diminished, as more cost-effective and less climate-dependent alternatives have become popular. However, Montana currently has many ETA systems and has begun to monitor their performance.

ET and ETA systems can be a very efficient means of on-site wastewater treatment if applied properly. There are several major limitations to these systems. For ET systems, the most obvious is the climatic requirement that evaporation exceed precipitation. A key and often overlooked point is that excess evaporation must persist every month of the year, or adequate storage must be included in the design. The ETA design can circumvent this requirement by discharge to the soil during higher precipitation periods (43).

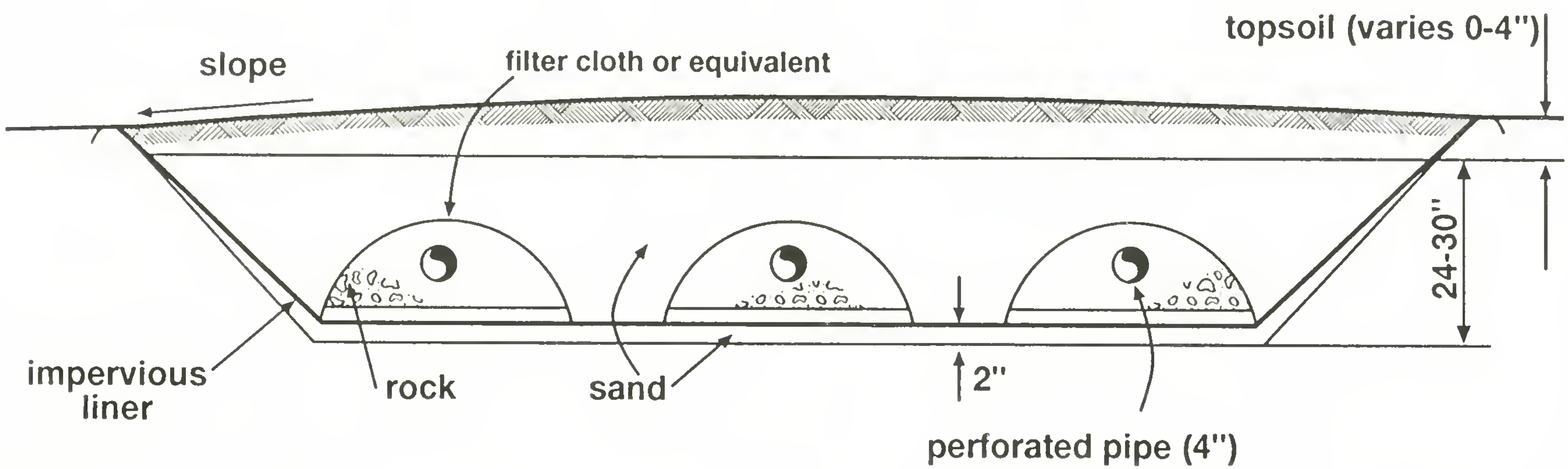

Figure 4. ETA Design (3)

As with sand mounds, system performance is based on whether or not any effluent surfaces. This approach is justified with ET and ETA systems which are designed to minimize the amount of effluent applied to the soil environment. However, ETA systems do discharge some effluent, and monitoring for performance parameters would be appropriate during wet periods. Available data for these systems are very limited, particularly current data. Also, there is little agreement on the basic assumptions used in design, making design comparisons difficult.

DESIGN CRITERIA

The more often-cited design directives vary with respect to criteria such as design storm intensity (10 or 25 year storm), and how much seepage or discharge is acceptable. Due to the site specificity of the designs, a comparative table as with mounds and sand filters would not be appropriate.

The hydraulic loading rate is the most important parameter that must be determined for design. Most designs incorporate total precipitation calculations into the loading rate.

Another important detail in these systems is the type of vegetative landscaping on the surface. Plants can transpire as much as 10 times the evaporation rate in a partially saturated soil (44). The ideal plant cover would be resilient to large fluctuations in available moisture, and would maximize transpiration. In Lake County, Montana blue spruce produces good results (45). Other good possibilities include grasses such as winter rye (43), and alfalfa (42).

EPA 1980 Design Manual (3)

The EPA Design Manual is the reference most often cited for design. Figure 4 shows the manual's ET design. In this design, the effluent enters at the bottom of the bed, and rises through capillary action and diffusion through the 1.5 ft of sand and gravel atop the laterals. In ETA systems some effluent also percolates downward.

The following ET recommendations are for a four-occupant home in Colorado. The recommended sand size is 50% weight smaller than or equal to 0.1mm (D_{50} = 0.1mm). The hydraulic loading rate is determined by establishing the smallest monthly difference between pan evaporation and precipitation rates. A slightly larger rate than this can be used for ETA systems, but it should not exceed soil absorption capabilities. For example, if a soil can accept .2 gpd/ft^2 and evaporation equals precipitation for a period, the recommended loading rate for design of an ETA system is .2 gpd/ft^2. The area required is determined by the predicted daily household outflow divided by the loading rate.

Montana Circular WQB-5 (1)

This design is conceptually different than the EPA design. Here the distribution laterals are placed on top of the bulk of the sand media (Figure 5). By discharging the effluent closer to the soil surface, evaporation potential may be increased. However, literature suggests that the biomat is most likely to form at the sand/soil interface (3). Therefore ponding will occur at the bottom of the media. The downward migration of applied effluent may interfere with the upward migration of evaporating ponded effluent. In this case, evaporation would be less than that in the EPA design. In such a system, most effluent would infiltrate. This would create a system where the majority of treatment is in the

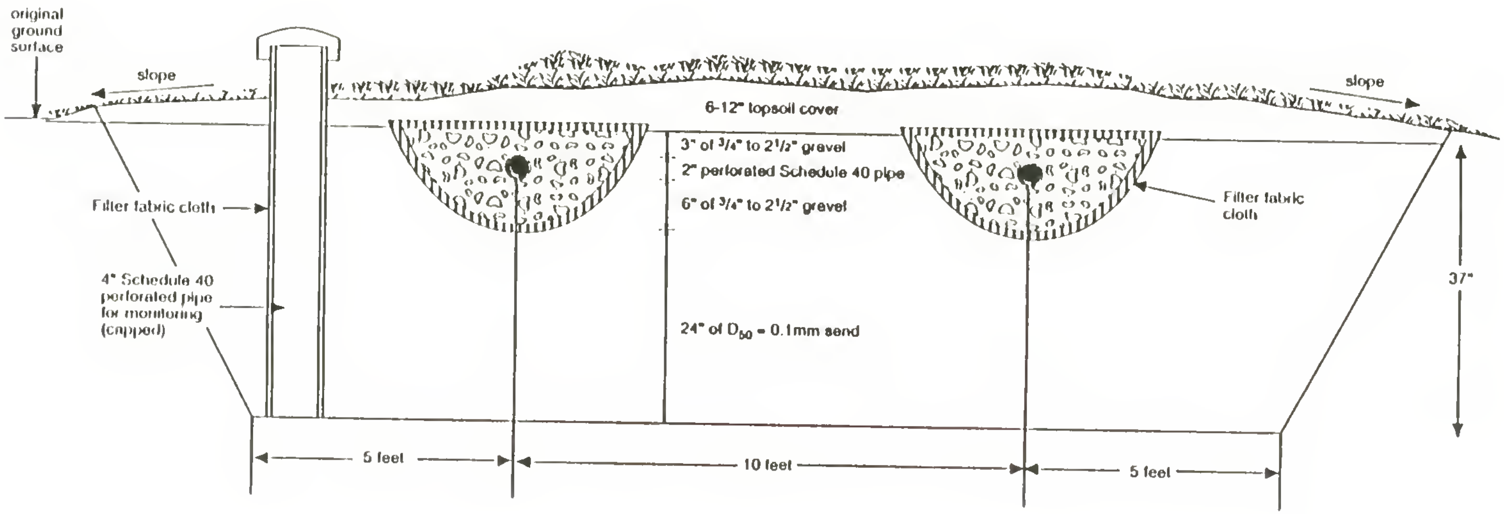

Figure 5. MT ETA Design (Lake County, MT DEQ)

sand and the native soil. Designs primarily utilizing treatment by infiltration are referred to in other states as "underground mounds." They are sized and designed in accordance with sand mound criteria.

Montana's design is based on the 10-year storm. Bed area is based upon a loading rate equal to the smallest difference between the monthly precipitation and pan evaporation rates. Storage is recommended if this criterion cannot be met. Recommended sand grain size is .05 mm $< D_{50} <$ 0.1mm (very fine sand). All other specifications are similar to the 1980 EPA Manual's design.

As mentioned, Lake County has had good success using blue spruce as part of the vegetative cover. Also, one important feature incorporated into most of the designs in Lake County is an inspection port for monitoring.

Small Flows Design Module #4 (44)

This manual is an elaboration of the 1980 EPA Design Manual (3) produced by the National Small Flows Clearinghouse. Most of the design criteria are the same as in the 1980 EPA Design Manual, but there is greater detail given for calculating dimensions and other criteria such as the evaporation rate. Example design problems are also included. This manual is mentioned herein not for contrasting design, but merely as a better reference than its 1980 predecessor.

Conclusions from Design Manuals

The contrast in design between the EPA and Montana criteria is indicative of the variation seen with ET and ETA designs. The differences may affect whether infiltration or

evaporation is the overriding effluent disposal mechanism. This may have an impact on how these systems will affect environmental quality.

ESTABLISHED PERFORMANCE EXPECTATIONS

Since the performance of ET and ETA systems is so closely tied to the specific climate of their location, there are no universal claims to their effectiveness. There are personal accounts from local authorities in Colorado (46) where they have always been problematic, and accounts from authorities in Arizona (47) where they evidently work flawlessly. There have been few studies involving effluent data collection to validate any claims. In an effort to evaluate performance, two of the most commonly-cited studies are reviewed below.

1978 EPA Study by Bennett & Linstedt (42)

This study looked at several mechanical and non-mechanical ways to utilize evaporation in wastewater disposal. The study evaluated ET systems, but not ETA systems. Twenty-nine small scale ET beds were evaluated.

Some of the most pertinent information from this study deals with the nature of evaporation in pilot beds. Bennett and Lindstedt measured summer ET bed evaporation as only 20% of the average pan evaporation rate. Evidently, at lower moisture levels interstitial capillary water did not rise to the surface and evaporate as quickly as saturated pore water. Therefore summer evaporation rates were slowed by the lack of mobile water in the pore space. They investigators also examined the effect of effluent temperature on evaporation. They concluded that the added heat from 50°C wastewater increased evaporation by

approximately 3%. All of the monitored systems experienced occasional ponding and the beds with the highest loading rate (0.1 gpd/ft^2) experienced the most frequent ponding.

This study was one of the earliest investigations into the potential use of evaporation as a means of wastewater disposal, and it uncovered many of the complexities involved in quantifying the process. Probably one of the most useful findings is the limited hydraulic loading rate ET systems can tolerate in a cool climate. Loading rates of 0.1gpd/ft^2 were found to be excessive. To maintain flows this low in ET beds, water conservation measures would be needed in the upstream households.

Bennett and Lindstedt would have advised against year-round use of ET systems for any part of Montana, based on their study of NOAA weather data for pan evaporation and precipitation (Figure 6). Their calculations indicate that parts of the eastern plains would be suited to summer use of ET systems. These investigators did not make recommendations concerning the use of ETA systems, but their directives indicate that if it were designed with adequate storage, an ETA system would be applicable in Montana.

<u>1982 Oregon Final Report</u> (15)

ET and ETA systems were evaluated in this long-term study, since Oregon does have considerable areas where annual evaporation potential exceeds rainfall.

Several arid areas were identified as having good potential for the non-discharging ET systems. The ET bed construction was contracted out to a local company. Almost all of the beds exhibited leaking, but the soils effectively drained the effluent and no health risk was posed. One bed was installed on impervious sandstone, and overflowed after 4 months of use.

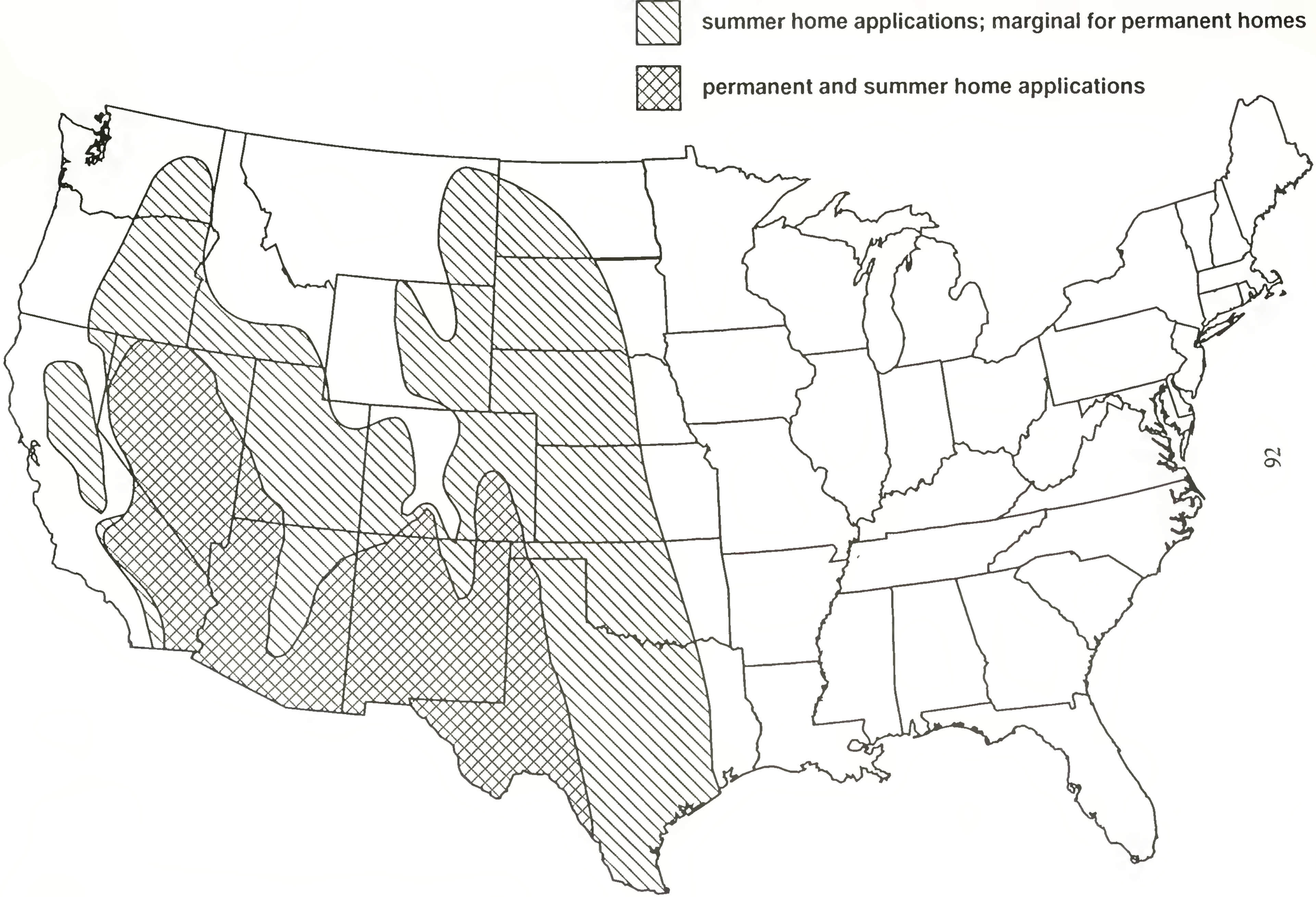

Figure 6. ETA Recommended Geographic Regions (42)

The ET systems did not perform satisfactorily. The leaking beds posed a potential health problem because of surfacing effluent, and the beds were generally too small to function safely on evapotranspiration. ET systems were dropped from the experimental program.

ETA systems were employed in areas of slowly permeable soils. The design varied from traditional designs, as the backfill media used was clay or a clay loam, not sand. Soil dikes were built around each bed. No systems overflowed the dikes, even though surface water did seep into some of the beds.

Properly constructed ETA systems functioned satisfactorily in suitable soils and where precipitation was less than 25 in/year. The ETA systems were said to function almost entirely as soil absorption beds. Poorly drained soils were found to be unsuitable for their construction.

CURRENT RESEARCH AND MONITORING

As mentioned, there has been very limited investigation into ET and ETA systems since the 1970's. However, there are attempts to examine their performance in Montana.

ETA systems in Montana

ETA system designs in Montana resemble what have been called "underground mound" systems, because the laterals are on top of the media. In these systems more effluent may be discharged into the native soil than occurs in systems having the laterals at the bottom. This bespeaks a need for monitoring these systems to determine the volume and quality of effluent applied to the soil profile. A 48 in. distance to the limiting soil condition is required for ETA systems, as with elevated sand mounds. However, the effluent infiltrating the native soil is much closer to this limiting condition with a buried ETA systems

than with elevated mounds. Therefore adequate treatment of the effluent before it infiltrates to native soil is critical. Another possible effect of topside lateral placement could be that the low HLR and small sand size allow the effluent to stay in the upper portions of the media. Evapotranspiration potential is higher in the upper portion of the media so this design adaptation would reduce the amount of effluent infiltrating the native soil profile. More monitoring and/or pilot studies would be beneficial in estimating which design is more effective at maximizing evapotranspiration potential.

There are many ETA systems operating in Montana and occasional effluent grab samples are collected. Only nutrient concentrations have been analyzed. For three beds sampled in 1995, the data were inconsistent (Table 22). One system showed very little nitrification, the second showed almost complete conversion of ammonia-N to nitrate-N, and the third system showed very little nitrogen in the system at any point. In that system, the low nutrient concentration could have been caused by groundwater infiltration diluting the waste stream. Phosphorus levels were low in all three systems.

With conflicting evidence presented by a limited amount of sampling it is very difficult to draw any conclusions about these systems' efficiency in Montana. More sampling would be required to establish the performance of ETA systems in treating wastewater before discharging it to the subsurface environment.

RAMIFICATIONS FOR MONTANA

The first question to be addressed is whether or not Montana has a suitable climate for these systems. Few of the design manuals reviewed recommend any parts of Montana for year-round use of non-discharging ET systems. While parts of eastern Montana have very

TABLE 22
PERFORMANCE DATA

ADAPTED FROM: MT DEQ data
System: ETA (3 systems)

REFERENCE: (sampling date)		2/16/95	7/25/95	2/16/95
HLR gpd/ft^2				
Temp.	infl.			
deg. C	effl.			
BOD5	infl.			
mg/l	effl.			
TSS	infl.			
mg/l	effl.			
AMMONIA-N	infl.			
mg/l	effl.	5.36	31.3	0.75
NITRATE-N	infl.			
mg/l	effl.	38.4	0.09	3.14
TKN	infl.			
mg/l	effl.	8.5	38.4	10.6
TOTAL N	infl.			
mg/l	effl.			
T. PHOSPHATE	infl.			
mg/l	effl.	1.17	7.17	3.54

low annual rainfall, there are no pan evaporation data available for cold weather months (a significant portion of the year). However, the Natural Resources Conservation Service has empirical formulas for estimating evaporation potential. ETA systems are feasible in all parts of Montana as mean annual evapotranspiration potential exceeds annual rainfall in all parts of the state (44). Storage for wetter months must be provided. However, if high groundwater is a problem, storage of effluent may allow insufficiently treated effluent to mix with the groundwater. Other limitations of these designs include large land requirements and very low hydraulic loading rates. Most manuals recommend that water saving plumbing devices be used in conjunction with ET systems.

One of the more intriguing observations in this review is how the ETA design used in Montana deviates from other recommended designs. The effect of placing the distribution laterals at the top of the media versus traditional design that place laterals at the bottom has not been investigated. Yet, counties incorporating this design report that they are pleased with the performance of these systems. Only by more consistent monitoring will the performance of this particular design be determined.

RECOMMENDATIONS FOR FURTHER STUDY

If installation of Montana-design ETA systems is to be continued, more complete monitoring is appropriate. The deviation of the design from standard designs may change how the system will function. Monitoring is necessary to establish that effluent has been adequately treated before infiltration to native soils. During periods of high groundwater there could be contact between partially-treated effluent and groundwater, if the media had

not adequately reduced contaminants. Monitoring ports placed at or near the sand-soil interface would allow sampling to determine this.

The use of trees is generally not recommended as vegetative cover for on-site systems. Tree roots have a tendency to grow towards their water source, the distribution laterals. While the use of the blue spruce around ETA systems in Montana has been effective at promoting evapotranspiration, investigation into whether or not the roots disturb the systems laterals after approximately ten years is suggested.

PACKAGE PLANT SYSTEMS

Pre-engineered secondary treatment units that use a mechanical means (usually aeration) of increasing the breakdown of organic material and/or reducing nutrients are commonly referred to as package plant systems. Figure 7 is a schematic of a package plant. During the last several years there has been an influx of new brands of package plant systems (PPSs) onto the market, with their developers seeking state approval. Simultaneously, these types of systems are coming under increased scrutiny. Package plant systems have been a source of controversy in the on-site wastewater treatment field recently. As a result, the then Department of Health and Environmental Sciences (the predecessor of the MDEQ) addressed the issue with regulatory revisions and new guidelines in 1995 (49). The new regulations call for very extensive testing by the manufacturers. The official policy statement on these systems says that package plants "should be discouraged." This policy is the result of documented poor field performance at various locations in Montana, and similar performance histories in other states. The additional testing requirements are seen as unfair by many manufacturers of these systems. Most claim that certification by third party organizations such as the National Sanitation Foundation (NSF) and American National Standard Institute (ANSI) is sufficient proof of their effectiveness. State officials reply that the field performance of these systems does not consistently stand up to the claims of manufacturers or results of certifying organizations. To investigate this discrepancy, it is necessary to compare field versus testing conditions. In this evaluation, the report on an individual system by a third party certifying organization is used to establish expected performance levels. These are then compared to field data and conditions to account for the poor performance records.

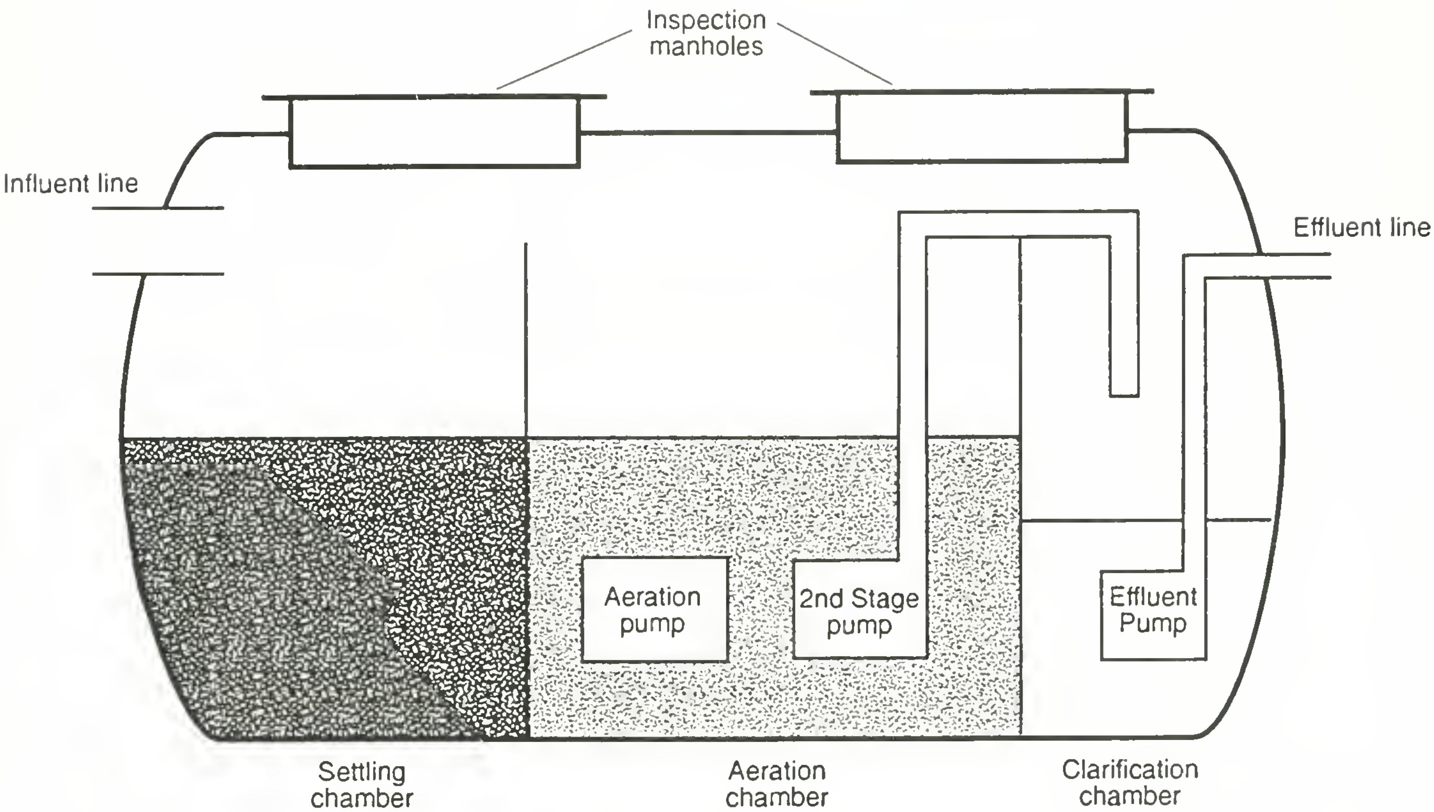

Figure 7. Aerobic Package Plant Schematic

DESIGN DIRECTIVES

The designs of the systems are as varied as the number of manufacturers. Most systems use a prefabricated media for attached growth processes, and aeration to increase bacterial metabolic activity. One important recent trend is that manufacturers are less likely to make claims that their system will operate maintenance free. Some manufacturers now recommend routine maintenance checks by one of their own trained technicians. In areas where this approach has been implemented, PPS reliability has been said to be significantly increased (50).

ESTABLISHED PERFORMANCE LEVELS

The number of PPS manufacturers is large, and growing. The Norweco system is the most widely used in Montana. The NSF report for this system is reviewed below.

NSF Report on the Norweco Singulair (model 820 & 900) (51)

These were systems certified by the NSF in 1978. They were tested according to NSF "standard 40" testing procedures, which entail running actual municipal wastewater through the system for a period of 6 months under conditions exemplary of normal household use. No regular maintenance is scheduled. There are several "stress tests" such as power failure, wash day loading, and return from a 9 day vacation with attendant shock loading. The particular six months in which this testing was conducted were winter months with

temperatures ranging from 46° to 62° F. One very important note is that testing was done only for BOD_5 and TSS. There was no testing for any type of nutrient removal.

The results of the testing show very good efficiency for these two parameters. The average BOD_5 reduction was 91% and the suspended solids reduction was 92%. The results of the stress testing showed that both systems maintained efficiency levels within NSF stress test limits (100 mg/l for TSS and 60 mg/l for BOD_5).

Review of the NSF results yields several conclusions. First, these systems can be expected to attain good removal efficiencies for organic material and suspended solids. Second, the testing does somewhat simulate field conditions. However, whether testing is done during winter or summer could affect the results if the system is temperature sensitive. Another important note is that an NSF certification does not mean the system has been tested for a wide range of parameters. Many package plant systems are sold based on claims of nitrogen removal. An NSF listing does not necessarily mean that they have been tested for nitrogen removal efficiency.

<u>1977 NSF Project in Kentucky</u> (52)

The applicability of NSF testing results to system field performance was investigated as early as 1977. In the mountainous region of Boyd County, Kentucky, thirty-six aerobic package plant systems of a single design were installed and monitored. A public sanitary district was formed to manage the systems and a licensed wastewater treatment plant operator was hired to monitor, service, and test the units. The test results were found to be "remarkably similar" to those obtained at NSF.

In the study's conclusions, the investigators pondered the reasons they often received reports of systems with dissimilar testing reports from those NSF obtained. They attributed this to the comparison of grab samples with daily composite results. The conclusion that it is inappropriate to compare grab samples with continuous sampling results is valid. No biologically-based system performs at constant efficiency in varied conditions. The manufacturers of package plant systems have a legitimate complaint in saying that occasional grab samples should not be used as sufficient evidence to discredit a system's performance.

This study also demonstrated the effectiveness of a maintenance and monitoring program. It showed that a population of systems can operate at maximum expected efficiency when maintained by a trained professional. This same conclusion could be drawn from many more recent monitoring projects.

CURRENT RESEARCH AND MONITORING

Monitoring of these systems is generally performed by the manufacturers. Each company has compiled great quantities of testimonials and data showing the excellent record of its system. It would not be valid to compare the peformances of different brands of systems to draw conclusions about all package plant systems, since the designs differ greatly. Most monitoring by government officials in other states targets problem systems, which would not accurately represent the overall performance of these sytems.

Package Plant Systems in Montana

Since the focus of this review is on the performance of these systems in Montana, the May 12, 1995 memorandum from the Water Quality Division (49) is the most pertinent

document. It clearly explains the history of package plant system performance in Montana. Repeated effluent quality violations led to the policy that discourages their use.

Many of the systems cited in the 1995 DHES study are small-community or commercially-applied systems. Manufacturers complain that this is not indicative of PPS performance for individual homes and smaller-scale use. Several grab samples have been collected from various single dwelling systems across Montana, and the data are very scattered (Table 23). Only effluent nutrient values have been analyzed. Effluent TKN values range from 91.7 mg/l to 16.9 mg/l. The randomness of the data could be due to the use of grab samples instead of continuous monitoring, or other causes. The reduced form of effluent nitrogen indicates aeration is almost completely ineffective. These data do not substantiate claims about the systems' small-scale effectiveness.

RAMIFICATIONS FOR MONTANA

Several conclusions should be drawn from the package plant study data. The NSF evaluation of the Norweco systems shows that NSF validation does not insure the system will be able to meet all nondegradation criteria. Which parameters were tested and what conditions existed during the certification evaluation are pertinent to the system's potential performance in the field.

It also appears that systems maintained by a trained professional can be expected to operate close to levels seen in certification testing. Several states now require a service contract between the homeowner and a manufacturer-certified maintenance person before a PPS will be permitted. Such regulation has greatly reduced the number of system failures (50). As quoted by a package plant system representative, "mandating service and

TABLE 23
PERFORMANCE DATA

ADAPTED FROM: MT DEQ data
System: Norweco PPS

REFERENCE: (sample date)		A*	A	A	A	B	B
HLR gpd/ft^2							
Temp.	infl.						
deg. C	effl.						
BOD5	infl.						
mg/l	effl.						
TSS	infl.						
mg/l	effl.						
AMMONIA-N	infl.						
mg/l	effl.	34	60	39.4	25.1		97
NITRATE-N	infl.						
mg/l	effl.	1.59	0.05	0.09	4.35	41.6	9.95
TKN	infl.						
mg/l	effl.	34.1	51.8	49.1	30.2	16.9	91.7
TOTAL N	infl.						
mg/l	effl.						
T. PHOSPHATE	infl.						
mg/l	effl.	7.46	9.65				11.9

*Different systems were sampled each time.. A = average of two systems; B = average of three systems.

maintenance is about the only thing the regulatory community can stipulate that will insure that nationally listed and certified products will perform in the field" (53).

As long as Montana does not have laws mandating maintenance contracts, erratic performance by package plant systems can be expected. Even if manufacturers meet the new requirements to obtain a permit, there is no assurance that homeowners will follow procedures prescribed in the operation and maintenance manual. Since Montana may lack the housing density to support a specialized package plant maintenance business, the current state policy of discouraging package plant use may be the only effective way to prevent problems.

RECOMMENDATIONS FOR FURTHER STUDY

Maintenance and monitoring contracts are relatively new requirements in the states that have implemented them. If there is long-term evidence from states such as Washington that these requirements allow package plant systems to operate without problems, then similar rules may be appropriate for Montana. A long-term survey of states that have mandatory maintenance and monitoring contracts could establish the contracts' effectiveness. Such a survey should concentrate on states with low population density, and should track whether maintenance contractors remain in business for more than a few years.

NITROGEN REMOVAL SYSTEMS

Possible contamination of water sources from sewage-derived nitrogen has received considerable attention in recent years. Nitrogen levels may drive the choice of an on-site wastewater treatment system: (i) where soil background levels of nitrates are documented to have risen recently, (ii) where surface waters are nearby, (iii) and where the primary source of drinking water is shallow groundwater.

The data from previously-discussed secondary treatment systems, such as sand filters, demonstrate the ability of these systems to nitrify ammonia-N in septic tank effluent. However, the resulting elevated concentrations of nitrate-N discharged into the soil profile may be of concern. Nitrate levels as high as 75 mg/l have been measured in a drainfield in Gallatin County (61). A recent trend in many states is the regulation of subsurface discharge of nitrates, often requiring less than 10 mg/l in the effluent of on-site systems. Montana's discharge regulations take into account local background levels of nitrates and the soil's ability to transport the nutrient at a site.

The wastewater treatment profession has responded with a variety of new systems designed to reduce nitrate levels. In biological systems this is done by reducing nitrate-N to nitrogen gas via biological denitrification. The requirements for this are: (i) oxidation of ammonium-N to nitrate-N via autotrophic microorganisms in an aerobic zone (ii) the presence of a subsequent anoxic zone with heterotrophic denitrifying bacteria, and (iii) an adequate carbon source for the denitrifying bacteria. The systems discussed in this section differ from nutrient removing package plant systems in that most of the materials are not pre-engineered (i.e. they can be found at most plumbing supply stores). These systems are

relatively new, so the basic questions of reliability, performance, and cost are currently being addressed.

Three systems are reviewed herein: (i) RUCK systems, (ii) Orenco's trickling filter/upflow filter, (iii) and Fluidyne's De-Nite unit. The RUCK System is the first advance beyond "the old rock tank" denitrification systems and is the most widely used. Orenco's system is being monitored in several areas and shows good preliminary data. Fluidyne is a Bozeman company whose patented new system is showing excellent results in Montana's climate.

The recirculating sand filter is often compared to nutrient removal systems, since it provides substantially-increased denitrification and total nitrogen removal. However, it is generally not engineered specifically for nutrient removal. Comparison of the performance data shows that while 50 - 60% Total N removal is common, RSFs do not consistently provide more nitrogen removal than systems reviewed in this section.

DESIGN DIRECTIVES

Each of these systems is unique in design. The common element is that each system provides aerobic environments for nitrification and anoxic conditions with a carbon source for denitrification. Since each system facilitates these differently, design comparisons are somewhat difficult.

<u>RUCK System</u> (54)

The original design calls for separation of greywater and blackwater in the household plumbing. Septic tank effluent flows into a sand filter for nitrification. The sand filter

effluent then flows into an anaerobic tank where the carbon source, the household greywater, is added for denitrification. Greywater separation is expensive, because of the extra household plumbing and the cost of two septic tanks. Therefore, adaptations have been made to use liquid soap injected into the system with a timed pump system as the carbon source.

Orenco Trickling Filter/Upflow Filter System (55)

Orenco integrates a trickling filter, an upflow filter, an ISF, and a shallow drainfield for maximum nitrogen removal. Individual components of this system can be used to enhance nitrogen removal at an existing site.

The first component is the trickling filter, a small compartment mounted on top of a standard septic tank, filled with a corrugated plastic media that has a high surface area-to-volume ratio. This allows a high density of attached microbial growth and subsequent nitrification in a smaller volume unit. The filtered effluent is then recirculated back into the septic tank, utilizing the raw wastewater as the carbon source and its oxygen-poor environment for denitrification.

The second mechanism is an upflow filter. The trickling filter was originally used in conjunction with an ISF. In original experimentation the ISF was actually discharging more nitrogen than was going into it, so the upflow filter was designed as an alternative to the sand filter. Preliminary testing has shown the upflow filter to be effective. It also reduces the land requirement and media costs compared to those of the ISF. An ISF can be used in addition to the trickling and upflow filter to further polish the effluent. A shallow drainfield is said to be another important mechanism for nitrogen reduction. In Orenco's tests, a final

50% reduction of Total N in the system's effluent was effected within the shallow drainfield (62).

De-Nite System (56)

The De-Nite system facilitates nitrogen removal in conjunction with frugal use of space and materials. Fluidyne's system circulates a portion of the septic tank effluent into a separate aerobic chamber for nitrification and filtration. The nitrified effluent is then recirculated back into the septic tank for denitrification. A unique feature of the system is the highly aerobic environment created in the separate chamber by a nonelectrical "lung." This allows the chamber to be covered by a topsoil layer for heat retention while maintaining consistent re-aeration. The advantage of this design is its simplicity. Maintenance and possible failures are reduced by limiting the number of pumps and mechanical devices. Costs are further reduced by using only one tank in addition to the septic tank.

ESTABLISHED PERFORMANCE EXPECTATIONS

Systems designed specifically to increase nitrogen removal are a relatively new phenomenon. There are no widely accepted values characterizing the quality of the effluent. No system type has been operating in enough diverse locations to establish widespread expected performance. One could argue that the RUCK system has enough operating data in the northeast to establish standard expectations, but its use in climates such as Montana's is limited. General expectations are that a system of this sophistication should: (i) reduce BOD_5 and TSS levels by 90% or greater, (ii) reduce total nitrogen to less than 10 mg/l, (iii) and provide some increased phosphorus removal.

CURRENT RESEARCH AND MONITORING

RUCK Systems (54)

RUCK systems are the most widely used of the three systems being reviewed. Their development and patenting have primarily been the work of Dr. Rein Laak. He has recently assembled a summary consisting of performance testimonials, design directives and general discussion.

The RUCK system has been field tested across the country in a variety of climate and soil conditions. Laak cites one hundred and seventy-eight RUCK systems in domestic use since 1977, twenty-eight laboratory and small field models and several commercial systems. Extensive data are available for systems throughout the northeast. Two exemplary monitoring projects from systems in Vermont and California as well as grab samples from one system in Montana are reviewed below.

Monitoring in Vermont consisted of extensive sampling over a one year period. The data (Table 24) are the composite results from eight homes. Greywater from the homes was used as a carbon source. Results show effluent mean Total N concentrations under 6 mg/l and mean total phosphorus at 3.52 mg/l. Influent concentrations are not included in the data, but influent total nitrogen concentrations are said to range from 50 to 120 mg/l. No temperature effect or lack of organic carbon is said to be evident. However, one may notice that BOD and TSS are much higher than seen in effluent from other types of secondary treatment. This is due to the addition of the carbon source in the denitrification chamber.

Two systems at commercial facilities in California were monitored extensively. A timed liquid soap injection system provided the carbon source. Influent total nitrogen concentrations were in excess of 150 mg/l. Some system adaptations were implemented to

TABLE 24
PERFORMANCE DATA

ADAPTED FROM: RUCK Systems, Inc (54)
System: RUCK

SYSTEM REFERENCE:		AVG. of 8
HLR gpd/ft^2		
Temp.	infl.	
deg. C	effl.	
BOD5	infl.	
mg/l	effl.	47.8
TSS	infl.	
mg/l	effl.	63.1
AMMONIA-N	infl.	
mg/l	effl.	3.52
NITRATE-N	infl.	
mg/l	effl.	< 0.352
TKN	infl.	
mg/l	effl.	5.45
TOTAL N	infl.	
mg/l	effl.	
T. PHOSPHATE	infl.	
mg/l	effl.	3.52

deal with the high strength of the influent. Final effluent total nitrogen concentrations were less than 5 mg/l.

Grab samples of effluent from three systems in Montana yielded inconclusive results. Two RUCK systems were tested only for nitrates. One system showed low nitrate levels that could indicate substantial denitrification, assuming most of the organic nitrogen was nitrified. A second system showed effluent Total N concentration at 22 mg/l. Apparently neither of these systems was operating as expected, but conclusions cannot be drawn from single grab samples.

RUCK systems have been shown to be able to reduce Total N levels by greater than 95% and TP by greater than 90% in commercial and residential applications. Some seasonal variations have been recorded. Effluent BOD and TSS levels can be elevated because of the addition of organic matter in the last stage of treatment prior to disposal. The application using soap instead of greywater has increased the economic feasibility of these systems. While RUCK systems have been embraced in the northeastern states and more recently in Arizona, they have been viewed skeptically in Montana. Construction costs rather than inadequate performance are the cause of skepticism (63). The installation cost of one Montana system was far greater than Laak's guidelines for system cost (68). Perhaps cost could be reduced with increased contractor knowledge of the system.

Orenco's Trickling Filter/Upflow Filter System (55, 62)

The recirculating trickling filter retrofitted to a septic tank is relatively compact, which makes it a very practical and cost efficient alternative for increased nitrogen removal. Data from testing of Orenco's recirculating trickling filter in Roseburg, Oregon and in

California are presented in Table 25. The upflow filter further reduces nitrates, and the application of a stratified ISF provides even further treatment (Table 25). Total nitrogen can be reduced to insignificant levels if the money is spent to incorporate all of these stages of treatment, but the recirculating trickling filter alone can generally provide treatment sufficient to meet nitrate-N discharge regulations. The cost and degree of disruption to retrofit with a trickling filter are nominal.

The level of treatment shown by the data in Ball's report (55) is substantiated by monitoring at Chico State University. Unfortunately, neither report provides insight into the cold climate performance of this system. The Gloucester On-site Demonstration Project has monitored a system incorporating an Orenco trickling filter with a shallow drainfield. The data (Table 25) show a 27% Total N reduction. This is well below anticipated levels. The investigator has reported that some site specific problems were rectified and later results were "closer to expected values" (21).

Effluent nitrogen can be almost completely removed with the application of all four stages of Orenco's nitrogen removal system (trickling filter/upflow filter/ISF/shallow drainfield). The cost and required maintenance of such a system might be cause for concern. Utilizing only the trickling filter in combination with the shallow drainfield may be a more economic application, reducing Total N levels by an expected 60 - 70%. This is sufficient for most applications. Preliminary monitoring shows Orenco's system to be capable of effectively removing wastewater nitrogen, but further monitoring in cold regions is necessary to establish reliable operating records for this system.

TABLE 25
PERFORMANCE DATA

ADAPTED FROM: Orenco Inc (62,55)
System: Recirculating Trickling Filter

STUDY REFERENCE:		Oregon (62)	Butte Co. CA (62)	Oregon (55)	Gloucester	additional treatment: (55) upflow filt.	U.F./ ISF
HLR gpd/ft^2							
Temp.	infl.						
deg. C	effl.						
BOD5	infl.				94		
mg/l	effl.			18	21	8	< 1
TSS	infl.				53		
mg/l	effl.			17	25	0	< 1
AMMONIA-N	infl.				16.5		
mg/l	effl.			5.6	14	1.2	< 1
NITRATE-N	infl.				3		
mg/l	effl.			4.1	2.4	2.5	7
TKN	infl.				28.9		
mg/l	effl.			11	19.1	2.9	< 1
TOTAL N	infl.						
mg/l	effl.	16	12 ± 7		21.5		

Fluidyne's De-Nite System

Fluidyne has been rigorously monitoring several units year-round to demonstrate high performance in Montana's climate (56). The monitoring includes temperature data from the atmosphere and in the nitrification unit. The systems are retrofitted to septic tanks at residences.

The data (Figure 8) show effluent nitrate/nitrite levels consistently below 10 mg/l. These concentrations show a slightly elevated trend during winter months, but not significant increases. Temperature in the De-Nite unit never dropped below 42°F, while air temperatures as low as 2°F were recorded.

The data for the De-Nite unit is impressive and costs are anticipated to be competitive with an ISF (56). While only a limited number of units have been field tested, the preliminary data show consistently effective nitrogen removal. Further studies of this system are being conducted by the University of New Mexico (56) and by Montana State University - Bozeman. These will provide additional data for establishing the De-Nite's effectiveness. If the De-Nite's long-term record sustains the performance seen in the preliminary data, this system would be extremely competitive for sites where nitrogen removal is required.

RAMIFICATIONS FOR MONTANA

There is a growing niche for nitrogen removal systems in states experiencing high rural growth. These systems attenuate organic carbon and turbidity efficiently, as well as nitrogen. For a system to be applicable in Montana, it must have demonstrated success in cold climates. Denitrification rates are very temperature sensitive (5) and lower temperatures in the system may greatly affect performance.

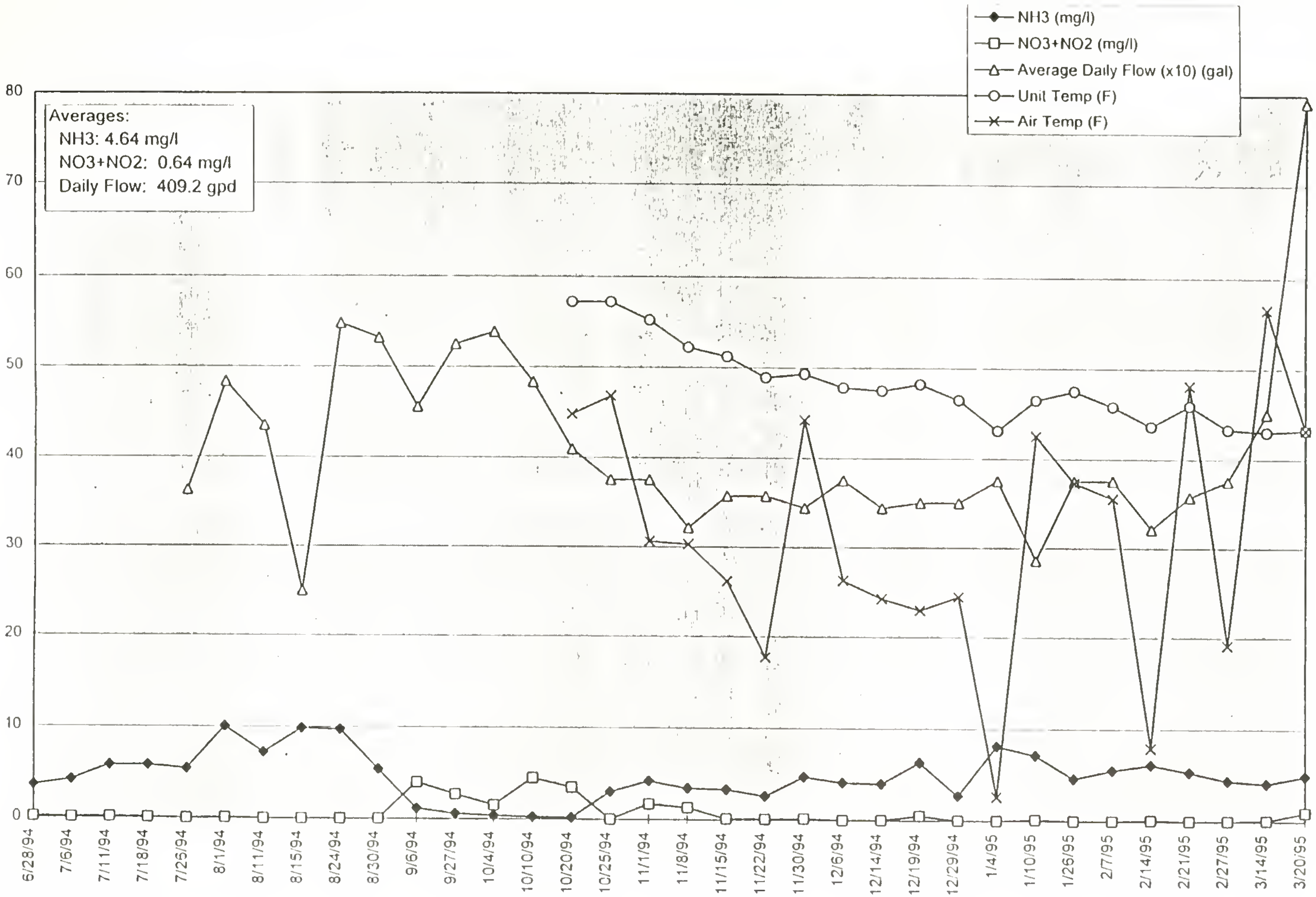

Figure 8. De-Nite Monitoring (Fluidyne, Inc.)

Each of the three systems reviewed has produced high quality effluent, with total nitrogen levels below 20 mg/l. Their cold-climate records are variable. As their performance records are filled out, it is anticipated that government and private sector acceptance will allow more widespread use of these systems. BOD and TSS removal rates are over 90%, as with other effective alternative systems. Also, these designs incorporate cost reducing options without sacrificing performance. These factors should make nitrogen removal systems an attractive option for any soil limited site, not just nitrate-sensitive areas.

RECOMMENDATIONS FOR FURTHER STUDY

In evaluation of nutrient removal, climate consideration is critical. Minimizing temperature fluctuations in the system improves performance. Research and development of methods to reduce heat loss in these systems would be worthwhile. A low cost way to maintain and possibly increase temperature in a nitrogen removal system would theoretically increase degradation rates and result in a further reduction of the system's size. The ways to approach this are as varied as the number of system designers, and will be left to the engineering creativity of the reader.

It is clear that, for the newer nitrogen-removal systems, there is a need for more performance data from full-sized systems operating through very cold winters. The monitoring should include air and effluent temperature, as well as the concentrations of nitrogen species in the influent and effluent of the secondary treatment unit.

CONSTRUCTED WETLANDS

Constructed wetlands systems (CWSs) are considered an attractive option for on-site systems in some situations because they combine wastewater treatment with aesthetic enhancement. Natural wetlands are generally not a viable alternative because regulations usually require their influent to meet surface water discharge standards. Therefore only constructed wetlands are considered in this review. It is estimated that about 1000 managed wetland systems are currently in operation (57). These are used in a variety of applications from treating mining waste to single home on-site sewage treatment. This review covers small community and single home on-site systems. Most of the research for CWSs has been in warmer states. There are arguably enough research data to establish accepted levels for CWS performance. However, many believe their viability in cold climates is questionable. Current research is addressing this question.

DESIGN CRITERIA

There are two general categories of systems employed in the U.S. A free-water-surface (FWS) system (Figure 9b) has the water surface exposed to the atmosphere, usually at depths of a few centimeters to 0.8 meters. A subsurface flow (SF) wetland (Figure 9a) is a basin filled with porous media, usually gravel. The media depth is typically 0.3 - 0.6 meters. The bottom is usually lined and a variety of vegetation is used with both systems (57). There are advantages to both types of systems. The SF system is believed to provide better biological treatment due to the increased presence of attached growth microorganisms. It also provides greater thermal protection. For domestic wastewater

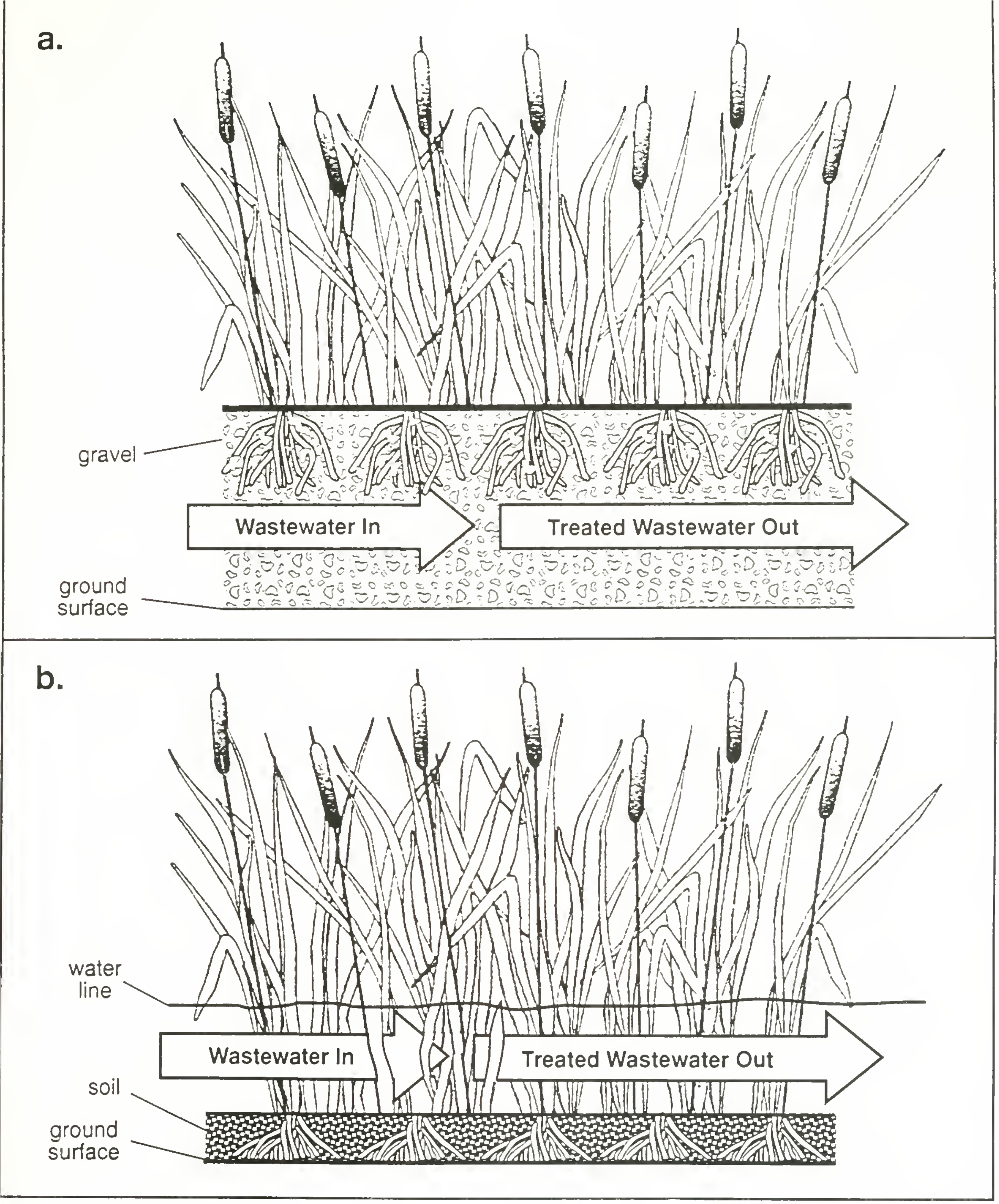

Figure 9. CWS Design (MSU Extension Service)

treatment, SF systems are often preferred as they reduce mosquitoes and human contact with the wastewater being treated. However, these advantages are often offset by the high costs of importing media and replacing clogged media. It is unlikely that an SF system could be cost competitive with a FWS system for design flows greater than 1 mgd, but these flows are not seen by what is usually characterized as a small community system.

When applied to treatment of domestic wastewater, constructed wetlands must be preceded by some sort of pretreatment, a septic tank at a minimum. They depend on higher plants, which can be difficult (and always take a long time) to establish.

There are three basic approaches to constructed wetland design, depending upon what the designer considers the most important mechanism for treatment (57). One approach depends upon a regression analysis of performance data from operating systems, another approach relates performance to areal loading, and a third approach assumes biological reactions are similar to other attached-growth wastewater treatment processes. There is no consensus as to which is best.

Each theoretical approach incorporates variations of the same components. The first component is the variety of plants, usually chosen for their climatic adaptability. The plant's function is primarily as a site for microbial attachment. They also aid in oxygen transfer and nutrient uptake. The second major component is the soil used. Soils affect the hydraulic regime as well as removal of ammonium and phosphorus. The third component is the beneficial organisms. The viability of bacteria and higher organisms such as protozoans can determine the system performance. Microorganisms are controlled by environmental factors such as substrate limitations, oxygen availability, and temperature.

Wetlands are often implemented as tertiary treatment for a specific contaminant. Maximizing the reduction of that parameter is then the main concern in design. There are specific models for maximizing treatment of BOD, nitrogen, and phosphorus (57). These models provide equations to develop design criteria such as retention time and surface area needed to reduce specific influent concentrations.

Operation and maintenance of a CWS consists mainly of rodent and mosquito control. Mosquitoes can be controlled naturally through stocking of fish and planting specific vegetation such as duckweed. Rodents can be controlled by keeping dikes and surrounding areas mowed.

ESTABLISHED PERFORMANCE LEVELS

Established performance levels for CWSs come from research in warmer states. Reviewed below are two separate sources. These put forth expected effluent levels of some parameters, and the biological mechanisms primarily responsible for degradation or removal of each. Results of current research in colder climate studies will then be compared to these expectations.

Natural Systems for Waste Management and Treatment (57)

The principal author of this text, Reed, is one of the premier authorities on aquatic and overland flow systems. Reed's conclusions are drawn from years of research on systems around the country.

Removal of BOD and TSS are said to be fast and efficient. Settlable organics are settled out in the FWS design and filtered out in the SF design, usually in the first few

meters of treatment. Dissolved and colloidal organics are continually removed by microbial action. Effluent from pilot studies has consistently been below 20 mg/l in BOD and TSS. Excess TSS can result in media pore clogging if influent hydraulics and pretreatment are not effective. BOD removal is primarily a physical process and will not be greatly affected by temperature fluctuations.

Nitrogen removal is complex in these systems, particularly since there is an organic nitrogen input from decomposing plants. Often nitrogen removal is limited by the availability of oxygen. In the FWS atmospheric re-aeration controls oxygen availability and thus nitrification efficiency. In the SFS, the extent of root penetration controls the re-aeration process. Alkalinity can also be a limiting factor in this process. Anoxic conditions required for denitrification are usually present in both types of designs. Carbon availability may be a problem as the denitrification will start after nitrification makes the nitrates available. Nitrification will only begin when BOD has been reduced, allowing nitrifying organisms to compete with other heterotrophic organisms for oxygen. Plant litter serves as a source of carbon, and carbon sources areusually adequate if temperature conditions are favorable. Despite the complexity of the process, nitrogen removal is said to range up to 79% in CWSs.

Phosphorus removal is said to be limited to the soil adsorption capabilities, which decrease with time.

Pathogen removal is mainly due to physical filtration provided by plants, media, and litter. Wetlands can achieve over 98% removal of coliforms with little seasonal effect, since this is mainly a physical process.

The performance of a CWS is dependent upon its design and operation as well as a host of microbial and biological interactions. Documented case studies show that a properly

designed system can produce effluent quality comparable to any other alternative on-site system. Temperature is said to adversely affect some nutrient removal processes, however.

1993 EPA Technology Assessment of SF Constructed Wetlands (58)

The EPA's assessment drew upon experience and data from CWS locations in Kentucky, Louisiana, Mississippi, Alabama and Virginia. The focus is on the SF design, as it was perceived to have multiple advantages over the FWS design. The sizes of the systems monitored ranged from a 1.7 mgd municipal plant to a 15,600 gpd domestic system.

BOD and TSS removal were found to be very efficient, with effluent concentrations consistently below 20 mg/l. Effluent suspended solids concentrations were greater than this where there were high influent TSS levels (> 50 mg/l) with no pretreatment. Most of the treatment for both parameters was said to occur in the first few meters.

Nitrogen removal did not show a simple trend. The data for ammonia removal were scattered, with many systems having increased ammonia concentrations in the effluent over the influents (58). Three factors identified as having the greatest effect on nitrogen removal were algae presence, hydraulic residence time (HRT), and availability of oxygen from plant roots. In the systems studied, nitrification increased with lack of algae, increased HRT, and greater root depths.

The removal of phosphorus was said to be related to the type of media used. If a gravel rich in iron and aluminum oxides is present, significant phosphorus removal occurs initially, but this decreases with time as the sorption capacity of the media is depleted.

Coliform removal in the SF wetlands was found to be 1 or 2 logs, generally satisfying discharge requirements of less than 200 cfu/100 ml.

Conclusions on Design Directives

Both references are in agreement on the expected levels of performance of a SF wetland. BOD and TSS removal are rapid and efficient, while a multiplicity of factors determine if any nitrogen removal is achieved. However, these systems are capable of significant reductions. Coliform removal is efficient and generally not subject to great variability.

However, data and observation are derived chiefly from warm climate locations. Since temperature has been shown to affect the transformation of certain parameters in CWSs, research in cold climate locations must be assessed to draw conclusions about the viability of these systems in Montana.

CURRENT RESEARCH

CWS performance in cold regions is the focus of many current research projects. One single home system monitoring project and one small community system monitoring project are reviewed here. There are several current large scale projects that should also provide evidence to the cold climate performance of CWSs. Two noteworthy projects are those conducted by Bernalillo County, New Mexico, where wetlands at high elevations are being monitored, and an EPA project monitoring several dozen CWSs in Colorado. These two projects are generating data that should be available by June 1996. Both of these projects should provide information that will be useful in determining the utility of constructed wetlands in Montana. Also, CWSs are used for the tertiary treatment of wastewater in several sugar beet processing plants in North Dakota. Specific data were not presented here,

since the effluent from sugar beet plants is not representative of domestic wastewater. However, the CWSs are operated year round with little freezing problems (64).

Aquaneering's Pilot Scale Project (59)

Aquaneering is monitoring a CWS at an individual residence in Laurel, Montana. The primary purpose of the system is to enhance nitrogen removal by establishing nitrification and denitrification zones.

The design of the system is simple. A series of trickling filters with a polyurethane foam media accept septic tank effluent and are aerated to promote nitrification. These are followed by a series of wetland cells constructed of specially plumbed bathtubs. The dissolved oxygen is expected to be depleted rapidly in the SF cells, and denitrification should occur. The effluent is then applied to a standard drainfield. A Plexiglas cover can be added over the wetland cells to promote solar heating in winter.

Preliminary data from the system are inconclusive. The nitrifying filters were only added recently when preliminary testing of wetland cell effluent showed significant ammonia-N concentrations. Also, the establishment of higher plants and denitrifying bacteria had been slow. System maturation is essential as carbon sources are derived naturally from decaying organic matter. Suspended solids and pathogen reduction has been over 90% effective.

Perhaps the most significant information to come out of Aquaneering's preliminary study is the temperature monitoring. The system was left uncovered throughout the winter of 1995-96 and did not freeze up. Average air temperature during the monitoring period was -3.4°C. Evidence that CWSs can operate in Montana without freezing is cause to continue

the investigation in establishing their cold climate performance and consider their viability as an alternative on-site system.

The Influence of Cold Climate Upon Constructed Wetlands in Norway (65)

This recent Norwegian study (1994) demonstrates the ability of subsurface flow CWSs to operate in very cold climates.

Three different systems treating domestic wastewater were constructed with varying types of pretreatment. The flow rate averaged 500 gpd. Aerobic pretreatment was utilized in some of the units. One modification for the cold climate was the use of a 90cm media depth although guidelines often suggest depths should not exceed 60cm. This allowed freezing of the upper layer while flow was maintained underneath. Using a heat loss model it was established that -20°C temperatures for a two week period are required to completely freeze an uninsulated system. However, 10cm of unsaturated soil was placed on top of the bed for insulation.

Recorded air temperatures dropped below -20°C, but the hydraulics remained satisfactory. BOD removal averaged 85%, 93% and 88% from the three treatment plants. Total N removal efficiencies averaged 48%, 59% and 83%. These values are comparable to other types of secondary treatment, particularly in colder climates.

This study is clear evidence that CWSs can not only maintain their hydraulic capacity but also maintain excellent performance in cold climates.

RAMIFICATIONS FOR MONTANA

The applicability of constructed wetlands to Montana has been dismissed in the past, as the climate was thought to be too severe. The operation of CWSs in North Dakota, in Laurel, Montana, in Norway and throughout Colorado suggests that this is not the case. A properly designed CWS can maintain flows throughout the winter in a climate such as Montana's. BOD, TSS and coliform reduction will remain effective as long as proper hydraulic conductivity is maintained. The remaining questions pertain to the performance, reliability, and practicality of these systems. Nutrient removal capabilities in colder climates have not been established, but continued research is addressing this issue. Large scale cold climate monitoring projects are underway and the initial data are due to be published soon (46, 47). Dr. Otto Stein at Montana State University - Bozeman is also conducting research on a CWS that should provide data for a more concrete assessment of CWS viability in Montana. The potential aesthetic and environmental gains from implementing this treatment option certainly validate this research.

RECOMMENDATIONS FOR FURTHER RESEARCH

All references on CWS designs emphasize the importance of fine tuning the hydraulic regime. This is often said to be the most critical design parameter. Currently there are a few rough guidelines for establishing system hydraulics, but further research is needed. More pilot scale studies would be helpful, but more experience from full scale systems is also needed, especially to illuminate the hydraulics of small community CWSs in colder climates. As more experience is gained from currently operating systems in other states, Montana should be able avoid the mistakes of others and increase the acceptance of these systems.

REFERENCES

1. Montana Department of Health and Environmental Sciences. 1992. Circular WQB-5: Minimum design standards for on-site alternative sewage treatment and disposal systems. Water Quality Division, Helena, MT.

2. Jellison, Bill (Montana state plumbing chief). Personal interview. 5 June 1995. MT. Dept. Commerce, Helena, MT.

3. United States Environmental Protection Agency. 1980. Design manual: onsite wastewater treatment and disposal systems, 1980. EPA 625/1-80-012.Office of Water Program Operations, Springfield, VA.

4. Report to the Chairman, Subcommittee on Investigations and Oversight, Committee on Public Works and Transportation, House of Representatives. 1994. Information on the use of alternative wastewater treatment systems. GAO/RCED-94-109. General Accounting Office, Washington, DC.

5. Metcalf and Eddy Inc. Tchobanoglous, G. (Ed.). 1979. Wastewater engineering: treatment, disposal, reuse (2nd edition). McGraw-Hill Publishers, New York, NY.

6. Whitmeyer, R.W. et al. 1991. Overview of individual onsite nitrogen removal systems. In: On-site wastewater treatment: proceedings of the sixth nationall symposium on individual and small community sewage systems, Chicago, Ill.. ASAE, St. Joseph MI. pp 143-154.

7. Montana Department of Health and Environmental Sciences. Water Quality Standards. Water Quality Division, Helena, MT.

8. Nor, Mohd. 1986. Performance of intermittent sand filters: effects of hydraulic loading rate, dosing frequency, media effective size, and uniformity coefficient. University of California-Davis.

9. Washington State Department of Health. 1995. Guidelines for sand filter systems. Office of Community Environmental Health Programs. Olympia, Washington.

10. National Small Flows Clearinghouse. 1985. Design module number 20: EPA technology assessment of intermittent sand filters.(WWBLDM20). WestVirginia University, Morgantown, WV.

11. Orenco Systems, Inc.. 1995. Design manual for sand filters. Sutherlin, Oregon: OSI.

12. Hines, J. and R.E. Favreau. 1974. Recirculating sand filter: an alternative to traditional sewage absorption systems. In: Proceedings of the national home sewage disposal symposium, Chicago, Ill. ASAE, St. Josephs, MI. pp 130-136.

13. Louden, T.L. et al. 1984. Cold climate performance of recirculating sand filters. In: On-site wastewater treatment: proceedings of the fourth national symposium on individual and small community sewage systems, Chicago, Ill.. ASAE, St. Joseph MI. pp 333-342.

14. Brandes, M., N.A. Chowdrey, and W.W. Cheng. 1974. Experimental study on removal of pollutants from domestic sewage by underdrained soil filters. In: Proceedings of the national home sewage disposal symposium, Chicago, Ill. ASAE, St. Josephs, MI. pp 29-36.

15. Ronayne, M., R.C. Paeth and S.A. Wilson. 1982. Final report: Oregon on-site experimental systems program. Oregon Department of Environmental Quality, Salem, Oregon.

16. Ball, H.L. 1991. Sand filters: state of the art and beyond. In: On-site wastewater treatment: proceedings of the sixth national symposium on individual and small community sewage systems, Chicago, Ill.. ASAE, St. Joseph MI. pp 105-113.

17. Ball, H.L. 1995. Sand filters and shallow drainfields. Orenco Systems, Inc. Sutherlin, Oregon: OSI.

18. Canody, J. Tennessee Tech evaluates septic tank filters. Small Flows. Summer 1995. National Small Clearinghouse, Morgantown, WV.

19. Hall, Seldon (Washington State Department of Health). Personal interview. 6 June, 1995.

20. Reed, Don (Nova Scotia Public Health Department). Personal interview. 14 June, 1995.

21. Jantrania, Anish (City of Gloucester, MA.). Personal interview. 21 June, 1995.

22. Roth, Dan (Municipality of Anchorage, AK.). Personal interview. 17 August, 1995.

23. Cagle, W.A., and Lynn Johnson. 1994. Onsite intermittent sand filter systems, a regulatory/scientific approach to their study in Placer County, California. In: On-site wastewater treatment: proceedings of the seventh national symposium on individual and small community sewage systems, Atlanta, GA. ASAE, St. Joseph MI. pp 283-291.

24. Louden, T.L., et al. 1989. Recirculating sand filters for cold regions. In: Proceedings of the summer international symposium on individual and small community sewage systems, Quebec, Canada. ASAE, St. Joseph MI. pp 1-10.

25. Louden, T.L., (Michigan State University). Personal communication. 28 July, 1995.

26. Roy, C., and J.P. Dube`. 1994. A recirculating gravel filter for cold climates. In: On-site wastewater treatment: proceedings of the seventh national symposium on individual and small community sewage systems, Atlanta, GA. ASAE, St. Joseph MI. pp 292-300.

27. Roy, C. (E.A.T. Environment Inc.). Lac-Nominingue, Quebec, Canada. Personal interview. 8 August, 1995.

28. Osesek,S., B. Shaw, and J. Graham. 1994. Design optimization of two recirculating sand filter systems for nitrogen removal. In: On-site wastewater treatment: proceedings of the seventh national symposium on individual and small community sewage systems, Atlanta, GA. ASAE, St. Joseph MI. pp 319-328.

29. Mote, C.R.. and E.E.Ruiz. 1994. Design and operating criteria for nitrogen removal in recirculating sand filter. In: On-site wastewater treatment: proceedings of the seventh national symposium on individual and small community sewage systems, Atlanta, GA. ASAE, St. Joseph MI. pp 339-346.

30. Stuth, Bill Sr., and C. Garrison. 1995. Comparison study between a crushed glass and a C-33 sand filter. Stuth Co., Maple Valley, WA.

31. Check, G.G., et al. The lateral-flow sand-filter system for septic-tank effluent treatment. Water Environment Research. November/December 1994. pp 919-928.

32. Swanson, S.W., and S.P. Dix. 1987. Onsite batch recirculation bottom ash filter performance. In: On-site wastewater treatment: proceedings of the fifth national symposium on individual and small community sewage systems, Chicago, IL. ASAE, St. Joseph MI. pp 132-141.

33. Converse, J.C., and E.J. Tyler. 1990. Wisconson mound soil absorption system: siting, design and construction manual. Small Scale Waste Management Project. University of Wisconsin-Madison, Madison, WI.

34. Washington State Department of Health. 1993. Guidelines for sand mound systems. Office of Community Environmental Health Programs. Olympia, Washington.

35. Converse, J. (University of Wisconsin-Madison). Personal communication. 24 August, 1995.

36. Harkin, J.M., et al. 1979. Evaluation of mound systems for purification of septic tank effluent. Water Resources Center. University of Wisconsin-Madison, Madison, WI.

37. Converse, J.C., and E.J. Tyler. 1986. Wisconson mound performance. Small Scale Waste Management Project. University of Wisconsin-Madison, Madison, WI.

38. Converse, J.C., and E.J. Tyler. 1984. Wisconsin mounds for very difficult sites. In: On-site wastewater treatment: proceedings of the fourth national symposium on individual and small community sewage systems, Chicago, Ill.. ASAE, St. Joseph MI. pp 333-342.

39. Converse, J.C., and E.J. Tyler. 1994. Nitrogen and fecal coliform removal in Wisconsin mound system. In: On-site wastewater treatment: proceedings of the seventh national symposium on individual and small community sewage systems, Atlanta, GA. ASAE, St. Joseph MI. pp 514-525.

40. Prager, Jay, and B. Glotfelty. 1994. Sand mound systems on slowly permeable soils: performance assessment. In: On-site wastewater treatment: proceedings of the seventh national symposium on individual and small community sewage systems, Atlanta, GA. ASAE, St. Joseph MI. pp 268-277.

41. Converse, J.C., and E.J. Tyler. 1987. Inspecting and trouble shooting Wisconson mounds. Small Scale Waste Management Project. University of Wisconsin-Madison, Madison, WI.

42. Bennett, E.R., and K.D. Linstedt. 1978. Sewage disposal by evaporation-transpiration. Municipal Environmental Research Laboratory, Office of Research and Developemnt. EPA-600/2-78-163. Cincinnati, OH.

43. Perkins, R.J. 1989. Onsite wastewater disposal. National Environmental Health Association. Lewis Publishers, Chelsea, MI.

44. National Small Flows Clearinghouse. 1983. Design module number 4. Onsite wastewater disposal: evapotranspiration and evapotranspiration-absorption systems (WWBLDM04). West Virginia University, Morgantown, WV.

45. Trussler, Pat. (Lake County, MT. Dept. of Health). Personal interview. 19 September, 1995.

46. Ward, Dr. Robert (Colorado Water Resources Institute). Personal interview. 17 January, 1996.

47. Bishop, Colin (Bernallilo County, New Mexico Dept. of Health). Personal interview. 14 Februrary, 1996.

49. Montana Department of Health an Environmental Sciences. May, 1995. Policy on package wastewater treatment plants. Water Quality Division, Helena, MT.

50. Lowe, Dave (Washington Onsite Sewage Association President). Personal interview. 28 August, 1995.

51. National Sanitation Foundation. 1990. Report on evaluation of Norweco, Inc. Singulair model 820 and model 900. Report No. S40-8-3. NSF, Ann Arbor MI.

52. National Sanitation Foundation. 1977. Report on the performance of aerobic wastewater treatment systems in Boyd County, Kentucky. NSF, Ann Arbor, MI.

53. Price, M (Norweco). Communication with B. Roth. 1995.

54. Laak, Rein. 1995. RUCK System: Summary of RUCK testing, performance discussion, design manual, approvals, some examples. RUCK Systems, Inc., Mansfield, CT.

55. Ball, Harold. 1995. Nitrogen reduction in an onsite trickling filter/upflow filter system. Orenco Systems, Inc, Sutherlin, OR.

56. Buchanon, Justin (Fluidyne, Inc.). Personal interviews, 1996.

57. Reed, S.C., and R.W. Crites, and E.J. Middlebrooks. 1995. Natural systems for waste management and treatment (2nd Ed.). McGraw-Hill Publishers, New York, NY.

58. U.S. Environmental Protection Agency. 1993. Subsurface flow: constructed wetlands for wastewater treatment. EPA 832-R-93-008. Office of Wastewater Enforcement and Compliance, Washington, DC.

59. Perkins, Roger (Aquaneering). Personal interview. March 3, 1996. Laurel, MT.

60. Kramer, M.H., et al. Waterborne disease: 1993 and 1994. AWWA Journal. March 1996. pp 66-80.

61. Peavey, H.S. 1978. Groundwater pollution from septic tank drainfields. Dept. of civil and engineering mechanics, Montana State University Bozeman, MT. Presented at: Blue Ribbons of the Big Sky Country Areawide Planning Organization, January, 1978.

62. Ball, Harold et al. 1995. On-site biological nitrogen removal using recirculating trickling filters. In: Bioremediation of Inorganics. Battelle Press, Columbia, Ohio.

64. Fifer, Jean (North Dakota Dept. of Health). Personal Interview. July, 1995.

65. Jenssen, P.D., T. Maehlum, and W.S. Warner. 1994. The influence of cold climate upon constructed wetlands: performance of treating domestic wastewater and landfill leachate. In: On-site watewater treatment: proceedings of the seventh international symposium on individual and small community sewage systems. Atlanta, GA. December 1994. ASAE, St. Joseph MI. pp 137 - 153.

66. Rupp, Gretchen. 1995. Onsite wastewater management options for Montana businesses. EB 136. MSU Extension Service, Montana State University - Bozeman, Bozeman, MT.

67. Jowett, E.C., and M.L.McMaster. A new single-pass aerobic biofilter for on-site wastewater treatment. *Environmental Science and Engineering*. January, 1994.

68. Cope, Ken (MT DEQ). Personal interview. September, 1995.

69. Walter, Greg. 1995. Data collected by Territorial Engineering, provided by Tim Read, Montana Dept. Environmental Quality.

APPENDIX

ALTERNATIVE ON-SITE SYSTEM SURVEY

Results from State-wide Survey

To establish the concerns regarding alternative on-site systems, one key resource needed to be tapped: Montana's county sanitarians. A written survey was developed to aid in establishing the "big picture" of alternative on-site system use in Montana. The extent of use of alternative systems throughout the state and the attitudes and perceptions of regulators towards these systems were the survey's focus. Eighteen out of fifty-two districts responded to the survey. Despite the lack of participation in the survey, the investigators feel the objective of the survey was accomplished. The responses confirmed the need for this review. While quantitative answers were requested in the survey, the objective was not to derive statistics about alternative system use. Researchers simply wanted to draw upon county sanitarians' practical experience with alternative systems to compliment the academic and technical papers reviewed.

The first section of the survey was intended to find out how many and what types of alternative systems are utilized in Montana. The sanitarians were also asked how these systems are regulated and how their performance is tracked. Some counties indicated a sharp increase in the number of alternative systems permitted in the last couple of years, while many reported few or no alternative systems added recently. The system most widely used was reported to be an ETA system. However, many responses appear to have included lagoons or pond systems in this category. The second most widely used system was reported to be elevated sand mounds with counties reporting up to 290 permitted systems. The third most frequently permitted system was reported to be the ISF, with up to 10 systems being

APPENDIX

ALTERNATIVE ON-SITE SYSTEM SURVEY

<u>Results from State-wide Survey</u>

To establish the concerns regarding alternative on-site systems, one key resource needed to be tapped: Montana's county sanitarians. A written survey was developed to aid in establishing the "big picture" of alternative on-site system use in Montana. The extent of use of alternative systems throughout the state and the attitudes and perceptions of regulators towards these systems were the survey's focus. Eighteen out of fifty-two districts responded to the survey. Despite the lack of participation in the survey, the investigators feel the objective of the survey was accomplished. The responses confirmed the need for this review. While quantitative answers were requested in the survey, the objective was not to derive statistics about alternative system use. Researchers simply wanted to draw upon county sanitarians' practical experience with alternative systems to compliment the academic and technical papers reviewed.

The first section of the survey was intended to find out how many and what types of alternative systems are utilized in Montana. The sanitarians were also asked how these systems are regulated and how their performance is tracked. Some counties indicated a sharp increase in the number of alternative systems permitted in the last couple of years, while many reported few or no alternative systems added recently. The system most widely used was reported to be an ETA system. However, many responses appear to have included lagoons or pond systems in this category. The second most widely used system was reported to be elevated sand mounds with counties reporting up to 290 permitted systems. The third most frequently permitted system was reported to be the ISF, with up to 10 systems being

reported in a county. Several package plant systems are concentrated in a few counties, and no constructed wetlands were reported.

The second section of the survey (questions 14 - 21) asked questions concerning sand filters. Only intermittent sand filters, not recirculating, are reported to be in wide use. Comments suggested they are reasonably reliable and the ratings for performance ranged from 5 to 8 (10 being the highest rating). One respondent indicated that in this county ISFs were being installed for nitrate reduction. This review had shown this to be a counterproductive tactic since an ISF will increase the amount of nitrate applied to the soil profile, and do little to promote the denitrification necessary to remove nitrogen from the wastewater.

The next section (questions 22 - 27) asked about elevated sand mounds. The responses rating the performance of this system type ranged from 3 to 9. Many responses indicated mounds are very reliable, while others commented they are not. One clear trend was evident: the responses from counties with larger numbers of systems indicated higher system reliability. This suggests that contractor knowledge and experience are critical to system performance, as concluded in this review. Survey respondents suggested that the system designers needed to be held accountable for the system's performance and that the land requirements for this system type sometimes made them impractical.

The next section (questions 28 - 34) pertains to the use of ET and ETA beds. Very few problems or failures were reported with this system type, but the performance ratings ranged from 3 to 8. Some reported newer design adaptations increased reliability.

Questions 35 - 38 inquired about the use of package plant systems. Of the two responses, one reported performance as advertised by the manufacturer. The second reported

that the increased power requirements did not justify the use of this system versus other more passive systems such as a sand filter.

Questions 40 - 43 inquired about the use of nitrogen reduction systems. There were few responses to this section, but one response stated that nitrogen reduction could be facilitated with little added cost, and should be done. This agrees with the conclusions in this review.

There were no responses to the questions concerning constructed wetlands.

Results from the Nation-wide Survey

An almost identical survey was sent to the wastewater agencies of twenty-two states including: Vermont, Illinois, Connecticut, Idaho, North Dakota, Iowa, Pennsylvania, Maryland, Ohio, Maine, and Delaware. The main criterion for selection was that the state's climate be considered relatively cold. Attempts were made to direct the survey to the attention of each states' most knowledgeable personnel on on-site systems. Eleven out of twenty-two states responded; many responses were lengthy. This is indicative of the interest in sharing information between states that was expressed by officials throughout this study. Again, the purpose was not to obtain statistical data about alternative system use, but to develop an understanding of regulators' opinions and attitudes towards these systems' performance. The responses validated this project's original assumption that more knowledge and experience are desired by agencies permitting alternative on-site systems.

A majority of officials responded that the number of on-site systems installed on marginal soils is increasing. Many of the systems in this review, sand filters in particular, were said to be no longer considered "experimental technology", but routinely permitted. A

majority of respondents indicated they felt current regulations adequately protect public health. However, a very common response was that there is a definite need for a maintenance and monitoring program.

Sand filters are widely utilized in most states surveyed. Sand filters are said to be reliable and most performance ratings were close to 10.

Elevated sand mounds are also utilized in most of the states responding. Most responses said these systems were reliable and most failures were attributable to owner abuse or poor siting or design. System performance ratings ranged evenly from 5 to 10 with an even distribution.

ET and ETA beds are not widely used. They are discouraged due to failures in four out of five responding states. Failure was attributed to weather extremes in most cases.

Package plants are widely implemented. One very revealing correlation is that states reporting good success with these systems all required a maintenance and monitoring contract. Many states that reported discouraging package plant systems did not have such requirements.

There was a wide range of responses to the section inquiring about nitrogen removal systems. A few respondents reported that nitrate contamination was not a concern. Others reported that this was an increasing concern and that attempts were in progress to utilize some of the newer nitrogen removal technology with on-site systems.

Seven officials responded that constructed wetlands are utilized in their states. All reported a limited experience from which to draw conclusions. Several stated the systems had been implemented less than a year ago and needed a year to mature. Evidence should be

forthcoming from states such as Maine and Vermont concerning the viability of CWSs in cold climates.

ALTERNATIVE ON-SITE WASTEWASTER TREATMENT SYSTEMS SURVEY

1. Job Title ______________________

b. Branch of State Government ______________________

2. Number of unsewered houses in your county? . . . . [ ]

a. Number added in the last 5 years? . . . . [ ]

b. Percentage of new houses (added last year) using on-site systems?

❑ 10%	❑ 30%	❑ 50%	❑ 70%	❑ 90%
❑ 20%	❑ 40%	❑ 60%	❑ 80%	❑ 100%

❑ Other: ______________________

	Yes	No
3. Do you see number of unsewered developments as a continually increasing trend in your county?	❑	❑
4. Are your county's regulations generally more explicit and demanding than state regulations in reference to alternative on-site systems?	❑	❑
5. Do county regulations require a registered engineer to design alternative on-site systems?	❑	❑

If no, what are the requirements? ______________________

____

____

6. Please give your best estimate of the number of "alternative" on-site systems in your county. . . . . [ ]

7. What is the breakdown as to the total number of each type of system? Please use categories below:

Intermittent/recirculating sand filters . . . . [ ]

Evapotranspiration beds . . . . [ ]

Aerobic package plants . . . . [ ]

RUCK or other specific nitrogen removal . . . . [ ]

Constructed wetlands . . . . [ ]

Other ______________________

8. Do county regulations require monitoring of these types of systems after a post-construction inspection? . . . . ❑ Yes ❑ No ❑ Conditional

9. Who is held accountable for this monitoring?

❑ Homeowner ❑ Engineer/Designer ❑ Installer ❑ County
❑ Other: ______________________________

10. With respect to on-site monitoring, how often is enforcement action (e.g. fines,shutdowns) taken to ensure accountable parties have complied with state regulations over the course of a year?

Number of regulatory actions per year . . . . [ ]

11. In your opinion, what has been the trend for accountability and enforcement of on-site regulations in your county over the last 3 years? . . . . ❑ Increasing ❑ Decreasing ❑ Steady

12. Do you feel current state guidelines and practices on on-site systems adequately protect watersheds and ultimately community health? . . . . Yes ❑ No ❑

brief explanation? ______________________________

____

13. Please write a brief note if you feel there are any unique aspects to your county's regulatory handling of on-site sewage treatment that might be useful to this study

____

____

____

The following questions (14-21) deal with intermittent and recirculating sand filter systems installed in your county. If there are none, please skip to question 22.

14. How many years have sand filters been in use in your county? . . . . [ ]

15. What percent of your sand filters are:

intermittent . . . . [ ] recirculating . . . . [ ]

16. Are there circumstances where one is preferred over another? Please explain. ______________________________

____

____

17. Do you know of any recent system failures?

intermittent systems? . . . . ❑ Yes ❑ No

recirculating systems? . . . . ❑ Yes ❑ No

18. What would you attribute the main cause of failure (for either type of system) to be?

❑ Poor design ❑ Poorly constructed ❑ Climatic causes (flooding etc.)
❑ Lack of maintenance ❑ Owner abuse
❑ Other: ______

	Yes	No
19. Do you know of any recent sand filter performance monitoring by your county?	❑	❑
by private companies?	❑	❑

20. What would you estimate the failure rate to be in your county?

recirculating sand filters . . .	❑ very little	❑ 5-10%	❑ 10-25%	❑ 25-50%	❑ over 50%
intermittent sand filters	❑ very little	❑ 5-10%	❑ 10-25%	❑ 25-50%	❑ over 50%

21. Overall, how would you rate the performance and reliability of these systems? . . . .

Poor 1 2 3 4 5 6 7 8 9 10 Excellent

Please give additional comments below on intermittent or recirculating sand filter use in your county.

______

______

______

The following questions (22-27) deal with above-ground sand mounds (Wisconsin mounds). If there are few or none in your county, please skip to question 28.

22. How many years have they been in use? . . . . ______

23. Have there been any recent system failures? . . . . ❑ Yes ❑ No

24. What would you estimate the rate of failure of sand mounds in your county to be? . . . . ❑ very little ❑ 5-10% ❑ 10-25% ❑ 25-50% ❑ over 50%

25. To what would you attribute the main cause of failure?

❑ Poor design ❑ Poorly constructed ❑ Climatic causes (flooding etc.)
❑ Lack of maintenance ❑ Owner abuse
❑ Other: ______

	Yes	No
26. Has there been any consistent performance monitoring of these systems by your county?	❑	❑
by private companies?	❑	❑

27. Overall, how would you rate the performance of these systems? . . . .

Poor 1 2 3 4 5 6 7 8 9 10 Excellent

Please give any additional comments below on elevated sand mound use in your county.

____

____

____

> The following questions (28-34) deal with the use of evapotranspiration beds. If there are few or none in use in your county, please skp to question 35.

28. How many years have these systems been in use in your county? .... [ ]

29. Have there been any recent system failures? .... ❑ Yes ❑ No

30. What would you estimate the rate of failure of evapotranspiration based systems to be in your county? .... ❑ very little ❑ 5-10% ❑ 10-25% ❑ 25-50% ❑ over 50%

31. Are most of the systems evapotranspiration nondischarging (i.e. lined beds using no native soil absorption, ET) or evapotranspiration-absorption (ETA)? ❑ ET ❑ ETA

32. Has there been any consistent monitoring for performance parameters by your county? .... Yes ❑ No ❑

by private companies .... Yes ❑ No ❑

33. Overall, how would you rate the performance and reliability of these systems? .... Poor 1 2 3 4 5 6 7 8 9 10 Excellent

Please give any additional comments on evapotranspiration-absorption systems. ______________

____

____

____

> The following questions (35-38) deal with aerobic package plant systems. If there are none in your county, please skip to question 39.

35. What does current county policy require (before permitting a package plant system)? If there is nothing required beyond state regulations, just note "SAS".

of the manufacturers? ____

____

of the homeowners? ______________________________

____

36. Do you know of any recent failures in your county? . . . . ❑ Yes ❑ No

37. To what would you attribute the main cause of failure?

❑ Poor design ❑ Poorly constructed ❑ Climatic causes (flooding etc.)
❑ Lack of maintenance ❑ Owner abuse
❑ Other: ______________________________

38 Is routine maintenance by a professional trained by the manufacturer carried out routinely for any package plant systems in your county? . . . . ❑ Yes ❑ No

39. In your opinion, what is the reliability of these systems? . . . .

	Poor								Excellent
1	2	3	4	5	6	7	8	9	10

Please give any additional comments below on aerobic package plant systems. ______________

____

____

____

> The following questions (40-43) deal with systems designed specifically to reduce nitrogen in septic tank effluent. If there are none in your county, please skip to question 44.

40. Have recent regulations (more stringent discharge parameters in sensitive areas) created an increase in the number of these systems? . . . . ❑ Yes ❑ No

41. What are the trade names of some of the more widely used systems (i.e. RUCK)?

____

____

	Yes	No
42. Has there been any consistent performance monitoring by your county?	❑	❑
by private companies?	❑	❑

43. Do you feel the issue of nitrogen discharges from on-site systems deserves more or less regulation? . . . . ❑ Yes ❑ No

brief explanation ______________________________

____

Please give any additional comment below on nitrogen removal systems, or on the issue of nitrogen removal in on-site systems in general

____

____

____

The following questions (44-48) deal with constructed wetlands. If these systems are not used in your county or are the jurisdiction of another department, please skip to question 49.

44. How many years have these systems been in use? . . . . [ ]

45. Have there been any on-going problematic issues in dealing with them (i.e. mosquitos, odors)?

____

____

46. Has winter weather and freezing been a cause of

hydraulic failure . . . . ❑ Yes ❑ No

insufficient treatment . . . . ❑ Yes ❑ No

47. Is cold weather storage of wastewater a mandatory design criterion? . . . . . ❑ Yes ❑ No

please explain ____

____

48. Have constructed wetlands lived up to the homeowner/community expectations in terms of adding aesthetic value to the property? . . . . ❑ Yes ❑ No

brief explanation ____

____

Do you have any comments or clarifications with regard to constructed wetlands?

____

____

____

49. Do you have any final comments or suggestions for this study? ______________________

____

____

____

____

____

____

____

Thank you for your assistance!!!

MONTANA
STATE UNIVERSITY

EXTENSION SERVICE

This project was partially funded by grants from the Montana Water Resources Center and the Montana Department of Environmental Quality.